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TABLE OF CONTENTS

	Author	Page
Influence of different combinations of tops and roots of susceptible and resistant varities of sugar beet on curly top symptoms and virus concentration	*C. W. Bennett*	553
The absence of carbonate in beet molasses	*J. B. Stark* *H. M. Wright*	566
Plastic protective coatings	*Allan Woods*	568
Sugar beet infection by more than one strain of curly top virus	*N. J. Giddings*	573
Correlation studies of chemical and morphological characters of sugar beet variety GW413	*Ernst Artschwager* *H. E. Brewbaker*	576
Sugar beet stand studies	*E. G. Eckroth* *C. E. Cormany*	583
Reloading of beet storage piles in Alberta, Canada	*Ray B. Evanson* *Wesley G. Smith*	586
Crystallization of sucrose with sonic waves	*Andrew VanHook* *W. F. Radle* *J. E. Bujake* *J. J. Casazza*	590
Preliminary studies on reciprocal recurrent selection in sugar beets	*LeRoy Powers* *R. E. Finkner* *C. W. Doxtator* *J. F. Swink*	596
Theoretical steady state distribution of an additive in sugar beet diffusers	*Fred Stitt*	611
Notes Section		632

Influence of Different Combinations of Tops and Roots of Susceptible and Resistant Varieties of Sugar Beet on Curly Top Symptoms and Virus Concentration

C. W. BENNETT[1]

Introduction

It is well known that the range of susceptibility to curly top in varieties of sugar beet is extremely great. Some varieties are very susceptible and greatly injured; others are so resistant that they show little or no symptoms. The curly-top virus is present in all parts of diseased plants and unquestionably direct injury is produced on both roots and tops. However, it has not been determined how much of the injury to tops is due to secondary effects resulting from direct injury to the root, and vice versa.

Since sugar beets graft readily it was thought that it might be possible to obtain information regarding reciprocal effects of roots and tops of resistant and susceptible varieties by switching tops of the two types of beets and inoculating with a virulent strain of curly-top virus.

Materials and Methods

The susceptible variety, R. & G. Old Type, and a very resistant variety, S. L. 68, were used for test. Roots about 6 cm. in diameter, and of uniform size and shape, were selected. A V-shaped segment about 5 cm. long and 2 cm. thick, cut to include the terminal bud, was taken from the crown of each beet. The crown segments were interchanged so that the following combinations were obtained: (a) susceptible top on susceptible root, (b) susceptible top on resistant root, (c) resistant top on susceptible root, and (d) resistant top on resistant root.

The segments were bound firmly in place and the beets were covered with moist sphagnum moss in boxes where they were kept at relatively low temperatures in an outside cage for a period of about 3 weeks. The beets then were placed in 8-inch pots and transferred to the greenhouse. In nearly all instances, union between the two parts of each beet was satisfactory and top growth proceeded normally.

[1] Pathologist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Salinas, California.

After vigorous tops had been produced on all plants, 25 viruliferous beet leafhoppers (*Circulifer tenellus* (Baker)) were caged on one leaf of each plant for 7 days.

Except as described later, the strain of the curly-top virus used was that designated by Giddings (3) [2] as strain 3. This strain of virus is relatively severe in its effects on the susceptible variety, R. & G. Old Type, but produces little or no evident effects on the resistant variety, S. L. 68. Plants were watched for the appearance of symptoms, and tests of virus concentration in parts of plants of the two varieties were made at intervals. These tests of virus concentration were made by the two methods as follows:

Method 1. A suitable leaf approaching maturity was selected and placed in a plastic cage. About 50 nonviruliferous beet leafhoppers were placed in each cage and allowed to feed 24 hours at a relatively high temperature. After the feeding period, 20 leafhoppers were removed from each plant and caged singly on seedling plants of sugar beets for 7 days. The percent infection produced on the inoculated seedling plants indicated the relative virus concentration in the tested part.

Method 2. The leafhoppers remaining in the cages on the test plants described above were allowed to feed an additional 48 hours, making a total feeding time of 72 hours. They were then removed and 20 leafhoppers from each cage were crushed, mixed with water, and centrifuged. The supernatant liquid was precipitated in 50 percent alcohol. The precipitate was removed by centrifugation, dried, and mixed with 1 cc. of a 6.8 mM sodium citrate solution to which enough sugar was added to make a 3 percent sugar solution. Nonviruliferous beet leafhoppers were allowed to feed on this mixture for 6 hours and then were caged singly on sugar-beet seedlings. The amount of infection obtained on these seedling plants is a relative measure of the quantity of virus the original leafhoppers were able to pick up from diseased beet leaves in a feeding period of 72 hours. Infection on seedling beets, therefore, reflects relative concentration of virus in the diseased parts on which the leafhoppers fed.

Infection and Type of Symptoms

In the first tests, 20 plants of each of the four graft combinations of the two varieties of sugar beet were inoculated. Infection was obtained on all plants except six in which a resistant top was grafter to a resistant root. Symptoms appeared on the susceptible tops in an average time of about 18 days regardless of whether the top was on a susceptible or resistant root. In

[2] Numbers in parentheses refer to literature cited.

the plants with resistant tops on susceptible roots, symptoms were observed on the lateral shoots that developed from the susceptible root, but no clearly defined symptoms were found on any part of the resistant tops. No symptoms were observed on the tops of any of the resistant plants grafted to resistant roots, but virus was recovered from 14 of the 20 plants by means of the beet leafhopper.

All of the inoculated plants were kept three months or more. During this period no significant differences in severity of symptoms were observed on plants with susceptible tops on susceptible roots as compared with plants with susceptible tops on resistant roots. The susceptible tops showed symptoms of about the same degree of severity regardless of the type of root to which they were attached. The resistant tops showed no clearly defined symptoms on either resistant or susceptible roots. Figure 1 shows

Figure 1.—Sugar beet plant with a resistant top (S. L. 68) grafted to a susceptible root (R. & G. Old Type). The two side shoots are from the susceptible root and show distinct symptoms of curly top, whereas the resistant central shoot shows no symptoms.

Table 1.—Results of Tests to Determine Relative Virus Concentration in Resistant and Susceptible Tops of Sugar-Beet Plants having Resistant or Susceptible Roots.

Method of Testing Relative Virus Concentration[1]	Test Plant Number	Seedling Sugar Beet Plants Inoculated and Infected from Plants of Indicated Top-root Combinations							
		Resistant Top[2] from R on S Plant		Susceptible Top[2] from S on S Plant		Resistant Top[2] from R on R Plant		Susceptible Top[2] from S on R Plant	
		Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.
		Number	Number	Number	Number	Number	Number	Number	Number
1	1	20	2	20	16	20	5	20	15
	2	20	0	19	16	20	1	20	17
	3	20	1	20	17	20	3	20	13
	4	20	8	19	15	19	1	20	16
	5	20	0	20	14	20	6	20	15
2	1	20	0	20	3	20	1	20	5
	2	20	0	20	9	20	1	19	9
	3	20	0	20	1	20	0	20	7
	4	20	0	20	4	20	1	20	7
	5	20	0	20	5	20	0	20	8

[1] Described under "Materials and Methods."

[2] R—resistant variety, S. L. 68; S—susceptible variety, R. & G. Old Type.

the type of growth produced by a resistant top on a susceptible root and also the effect of the disease on side shoots from the susceptible root.

Relative Virus Concentration in Tops of Plants of the Four Graft Combinations

Five plants of each of the four graft combinations were selected for determination of relative virus concentration in the tops. All of these plants were known to be infected either through presence of symptoms or through previous tests in which virus was recovered by means of the beet leafhopper.

A summary of the results of tests of 5 plants of each of the four types of grafted plants by each of the two methods of testing virus concentration is shown in Table 1. The results obtained clearly indicate that the virus content of the susceptible tops was appreciably higher than that of the resistant tops. It seems evident from these results that the type of root to which the resistant or susceptible top was attached had no detectable influence on the virus content of the top portion of the plant.

Relative Virus Concentration in Susceptible and Resistant Shoots of the Same Plant

Shoots were produced from various parts of the crown of nearly all of the grafted plants. In cases where desired, this gave two types of shoots on each plant: a main shoot of the scion variety and one or more shoots of the stock variety. This made possible the testing of virus concentration in resistant and susceptible shoots growing on the same root system under practically identical conditions. After certain preliminary tests, plants, each with a resistant top grafted to a susceptible root from which a side shoot had been produced, were selected for testing relative virus concentration in the two varieties of sugar beet.

A summary of 5 replications of this test, each test including 5 grafted plants, is shown in Table 2. These results indicate clearly that the concentration of virus was much higher in the shoots of the susceptible variety than in the shoots of the resistant variety.

Effect of Defoliation and Darkness on Concentration of Virus in Resistant Tops

Seven of the most vigorous plants with resistant tops on susceptible roots were selected for further tests. The relative virus content of the resistant top and a susceptible side shoot from the susceptible root of each plant was tested by the two methods already described. Following these tests all leaves were removed from the resistant top and the defoliated crown was placed in

Table 2.—Results of Tests to Determine Relative Virus Concentration in Resistant and Susceptible Sugar-Beet Shoots Growing on the Same Root System.

Method of Testing Relative Virus Concentration[1]	Test Plant Number	Leafhoppers that Obtained Virus from Resistant Shoots		Leafhoppers that Obtained Virus from Susceptible Shoots	
		Inoculated Plants	Plants Infected	Plants Inoculated	Plants Infected
		Number	Number	Number	Number
1	1	100	8	100	78
	2	100	2	100	56
	3	100	11	100	69
	4	100	19	100	88
	5	100	5	100	82
2	1	99	3	95	50
	2	100	4	100	39
	3	100	0	100	31
	4	100	0	100	18
	5	100	5	99	35

[1] Described under "Materials and Methods."

the dark. The susceptible side shoots remained under normal conditions of light prevailing in the greenhouse. Growth from the darkened resistant crown was reasonably satisfactory in all cases and wholly etiolated leaves were produced. A typical plant, after removal of the crown from the dark chamber, is shown in Figure 2.

Vein clearing probably would not show in etiolated leaves but vein swelling and distortion, if produced, should be evident. Under the conditions of the test, however, none of the etiolated leaves of the resistant tops showed recognizable symptoms of curly top.

After the resistant tops had been in the dark for periods varying from 3 to 5 weeks, the resistant top and a susceptible side shoot of each plant were tested for virus concentration using the two methods already described. Following these tests the plants were returned to normal light conditions and the resistant top allowed to resume normal growth. After the resistant top had presumably produced enough growth to enable it to again assume its normal relationship to the plant as a whole, the resistant top and a susceptible side shoot of each plant, except as indicated, again were tested for virus content.

The results of these tests are shown in Table 3. The indicated differences in concentration of virus in the resistant and susceptible shoots of the same beet before defoliation of the resistant top are striking in both methods of test, the concentration of

Figure 2.—Sugar beet plant with a resistant top (S. L. 68) grafted to a susceptible root (R. & G. Old Type). The leaves of the resistant top were removed and the crown placed in a dark chamber which permitted the susceptible side shoots to remain in the light. No symptoms of curly top were produced on the etiolated leaves but tests indicated that the concentration of curly-top virus increased greatly during the period in darkness.

virus in the resistant part being relatively very low as shown by the percent infection produced on seedling plants. It is evident, however, that after the resistant parts were defoliated and a new top was produced in the dark, virus in considerable concentration was present in the resistant part. It is possible, of course, that this virus increase was due to increased multiplication of the virus under the altered environmental conditions to which the tops were subjected, but it seems more probable that it resulted from movement of materials into the shoots from the susceptible root or from susceptible shoots in the light which were supplying elaborated food materials for growth of the etiolated top.

It is of interest that this increased concentration of virus in the resistant part did not result in the production of symptoms of disease under the conditions of the experiment. After the resistant tops were exposed to the light and allowed to grow under

Table 3.—Results of Tests to Determine Concentration of Curly Top Virus in Resistant and Susceptible Shoots of Sugar Beets on Susceptible Roots (1) under Normal Conditions of Growth, (2) after the Resistant Shoot was Defoliated and Placed in the Dark, and (3) after the Resistant Shoot had Recovered following Return to the Light.

Method of Testing Relative Virus Concentration[1]	Test Plant Number	Under Normal Conditions of Growth with Respect to Light				Resistant Shoot Etiolated Following Defoliation and Growth in Dark				Two to 3 Weeks after Return to Normal Light of Greenhouse			
		Resistant Shoot		Susceptible Shoot		Resistant Shoot		Susceptible Shoot		Resistant Shoot		Susceptible Shoot	
		Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.
		Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number
1	1	20	8	20	17	20	14	19	17	20	10	20	18
	2	20	0	20	17	20	12	20	13	20	5	20	10
	3	20	1	19	15	19	14	20	15	20	3	20	15
	4	20	4	20	18	19	16	19	15	—	—	—	—
	5	20	0	20	17	20	13	20	15	20	12	20	15
	6	20	0	20	20	20	11	20	9	18	9	19	15
	7	20	3	20	15	20	19	20	14	—	—	—	—
2	1	20	0	20	4	20	3	20	7	20	1	19	5
	2	20	0	20	6	19	3	19	1	20	0	20	9
	3	20	0	20	6	20	6	20	4	20	0	20	5
	4	20	0	19	11	18	13	20	2	—	—	—	—
	5	20	1	19	5	20	5	20	6	—	—	—	—
	6	20	0	20	13	20	2	19	3	20	0	20	6
	7	20	0	20	8	19	7	20	4	—	—	—	—

[1] Described under "Materials and Methods."

Table 4.—Results of Tests to Determine Comparative Concentration of Virus Strains 1 and 3 in Resistant (Grafted) and Susceptible Shoots of the Same Root of the Susceptible Variety.

Method of Testing Relative Virus Concentration[1]	Test Plant Number	Virus Strain 1				Virus Strain 3			
		Resistant Shoot		Susceptible Shoot		Resistant Shoot		Susceptible Shoot	
		Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.	Plants Inoc.	Plants Infect.
		Number	Number	Number	Number	Number	Number	Number	Number
1	1	20	9	20	9	20	0	20	20
	2	20	0	20	16	20	7	20	15
	3	20	12	20	15	20	1	19	14
	4	19	12	20	12	20	0	20	18
	5	19	12	16	14	20	3	20	15
	6	19	11	20	12	20	0	20	17
	7	18	5	14	7	20	0	20	20
	8	19	5	17	11	20	0	20	9
2	1	20	7	20	0	19	0	17	7
	2	20	5	17	3	20	2	19	13
	3	20	5	20	4	20	0	19	5
	4	18	2	20	0	20	0	20	17
	5	20	2	20	3	20	1	20	8
	6	20	0	20	4	20	0	19	7
	7	20	2	20	5	20	0	20	13
	8	20	1	20	0	20	0	20	4

[1] Described under "Materials and Methods."

normal conditions, their virus content dropped and relative virus concentrations approaching those found at the beginning of the test were found in the resistant and in the susceptible shoots.

Comparative Concentrations of Virus of Strains 1 and 3 in Resistant and Susceptible Shoots

In contrast to virus strain 3, which produces almost no symptoms on the beet variety, S. L. 68, strain 1 as described by Giddings (3) produces distinct vein clearing and clearly evident vein swelling and distortion on leaves of this variety. The two strains produce symptoms of about equal severity on other varieties of sugar beet. Tests were made to determine whether symptoms of greater severity produced on plants of the variety S. L. 68, by virus strain 1, are associated with greater concentrations of virus. For these tests, plants with susceptible roots and resistant tops were used. Each of the plants selected also had one or more side shoots developed from the susceptible stock portion of the grafted plant. One lot of plants was inoculated with virus strain 1 and a second lot with virus strain 3.

As in the earlier experiments, strain 3 produced no symptoms on the resistant top but produced symptoms of medium severity on the shoots that developed from the susceptible root. Strain 1 produced mild but clearly evident symptoms on the resistant tops and symptoms of medium severity on shoots that developed from the susceptible roots.

About six weeks after the plants were inoculated, 7 infected plants from each of the two lots inoculated with the two different strains of the curly top virus were selected and tests of virus concentration were made in resistant and susceptible shoots of each plant by the methods already described.

The results of these tests are shown in Table 4. As in previous experiments with strain 3, much more virus was recovered from the susceptible than from the resistant shoots. With plants inoculated with strain 1, however, the amount of virus recovered from the susceptible shoot was perhaps not significantly different from that recovered from resistant shoots, showing that virus strain 1 occurred in the resistant tops in concentrations approaching or equal to those in the susceptible variety. Apparently, in S. L. 68, the concentration of virus strain 1 was considerably higher than the concentration of virus strain 3.

Discussion

It seems obvious from the results obtained from this series of tests that, under the conditions employed, the degree of resistance of beet roots on which tops were growing had no appreciable effect on the severity of symptoms produced by curly-top virus

strain 3 and that, so far as determined, there was no interchange of material between resistant and susceptible parts that affected the resistance or susceptibility of the tops of either variety. Also, in each variety of beet there was established and maintained a concentration of virus that, in the tops at least, was more or less constant for the variety. This concentration was very low in the resistant variety and relatively high in the susceptible variety. Under normal conditions of development, virus concentration in tops appeared to be independent of the root system on which the tops were growing.

The effects of tops on the root system are more difficult to determine and in these experiments the effects were not obvious. It has been shown in several instances that when a top with a high concentration of virus is placed on a stock or root system of a species or variety normally incapable of supporting a high concentration of virus, marked increased effects are produced on the resistant part. For example, the yellow-vein strain of the curly-top virus produces marked symptoms on the new growth of both *Nicotiana glauca* Graham and *Datura meteloides* DC, when infected Turkish tobacco scions are grafted to these species and allowed to grow in a position to supply carbohydrates and virus to the stock (1). Both *N. glauca* and *D. meteloides* are immune to the yellow-vein strain of the curly-top virus under normal conditions. Also, sweet orange appears to be able to support a high concentration of the tristeza virus, whereas sour orange apparently develops a lower concentration (2). Neither type of orange is injured appreciably when growing on its own root system, and trees of sour orange on sweet orange roots systems are likewise not seriously injured. Trees of sweet orange on sour orange roots, however, are killed by the tristeza virus.

On this basis it was thought that perhaps beet plants with a susceptible top on a resistant root might be seriously injured by virus strain 3 by a greatly increased concentration of virus that might be present in the resistant root as a result of movement of materials into the root from a susceptible top having a high virus content. It seems logical to expect that concentration in the resistant root did rise in plants of this combination, since the virus concentration in resistant tops on susceptible roots increased appreciably when the tops were grown in the dark and forced to obtain their food supply from susceptible roots.

The results of determinations of comparative concentrations of virus of strains 3 and 1 in selection S. L. 68 suggest a correlation between virus concentration and severity of symptoms. This correlation did not hold, however, in the etiolated tops of selec-

tion S. L. 68. This poses questions with respect to the basic nature of the virus strains involved and in their relationship to the plant. It does not seem probable that failure of strain 3 to produce symptoms on etiolated leaves of plants of S. L. 68 is due wholly to the etiolated condition of the leaves, since vein swelling and distortion caused by other strains of the curly-top virus are as marked on etiolated as on green beet leaves. It is possible, of course, that the higher concentrations of strain 3 in etiolated leaves of S. L. 68 resulted from movement of more or less inert virus from other parts of the plant and that different results would have been obtained if the virus had increased wholly in the etiolated leaf. In view of the experience with other viruses, however, which have produced symptoms on resistant parts under similar conditions, it seems more probable that there may be marked differences between strains 3 and 1 in their ability to adversely affect plants of selection S. L. 68, even when present in equal concentrations.

Summary

Two varieties of sugar beets, R. & G. Old Type, very susceptible to curly top, and S. L. 68, very resistant to curly top, were used to study the effect of different root and top combinations of the two varieties on their reaction to the curly-top virus in the four possible graft combinations of tops and roots of the two varieties.

Curly-top virus strain 3, which produces relatively severe symptoms on the susceptible variety and almost no symptoms on the resistant variety, was used to inoculate a series of plants of the four graft combinations.

Under greenhouse conditions, the variety of root on which the top was growing apparently did not appreciably influence rate of growth or type of symptoms on the tops.

Virus concentrations were much higher in susceptible tops than in resistant tops and, under normal conditions of growth, virus concentration appeared to be determined by the variety and to be unrelated to the degree of resistance of the root on which the top was growing.

When plants composed of a resistant top on a susceptible root were defoliated and new resistant tops allowed to grow in the dark, the virus concentration increased in the etiolated resistant tops to a point approaching that in susceptible shoots in the light and attached to the same root system. When the resistant tops were returned to the light and allowed to resume growth under

normal conditions, the virus concentration decreased appreciably. Although the etiolated leaves had a high virus concentration, no symptoms of curly top were observed.

In tops of the resistant variety, S. L. 68, the concentration of virus strain 1, which produces clearly recognizable symptoms on this variety, was greater than that of virus strain 3 which as a rule produces no symptoms.

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The Absence of Carbonate in Beet Molasses

J. B. Stark and H. M. Wright[1]

Reports on the composition of European and American beet molasses list carbonate as one of the major inorganic constituents (1, 2)[2]. It is not clear whether the molasses samples contained carbonate or whether it was one of the major constituents of the ash and produced only by ashing a mixture of organic and inorganic material. If the latter is the case we may be unduly concerned about the effect of carbonate on sucrose solubility and crystallization rate (3).. It might appear that carbonate would be a normal constituent of molasses, since carbon dioxide is used during processing and in many cases sodium carbonate is added to preserve the alkalinity of the juice. However, if sufficient calcium ions are available, carbon dioxide or carbonate should be precipitated as calcium carbonate. We would expect to find carbonate occurring as a molasses component only when adequate calcium or other suitable ions are not present or when the acidity is high enough to prevent the formation of insolble carbonates.

Because of its effect on crystallization (3) the amount of carbonate present was selected as one phase of a composition study of 1956 molasses. One 1955 and eleven 1956 samples of final factory molasses representative of the various beet processing areas of the country were examined. Samples were selected from factories using non-Steffen, Steffen, barium and ion exchange processes of purification.

The procedure used for the determination of carbonate was as follows. One gram of molasses was diluted to 50 ml. with distilled water and a 5 ml.. aliquot introduced into a Van Slyke manometric apparatus. After degassing the solution, one ml. of a one-to-one sulfuric acid solution was introduced and the mixture allowed to react for one minute under reduced pressure. The volume of gas liberated was adjusted to two ml. and the pressure measured. The gas was then transferred to a Hempel pipette containing 10 percent sodium hydroxide solution and after adsorption of the carbon dioxide the gas was returned to the Van Slyke apparatus for measurement of the pressure at the two ml. volume. The amount of carbonate present in the sample may be calculated from the difference in pressure before and after the gas is treated with the sodium hydroxide solution.

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[1] Western Utilization Research and Development Division, Agricultural Research Service, United States Department of Agriculture, Albany 10, California.

[2] Numbers in parentheses refer to references.

Under these conditions a decrease in pressure of one cm. corresponds to about 0.05 mg. of carbon dioxide or 0.07 mg. of carbonate in the molasses aliquot. This amount would be equivalent to 0.07 percent carbonate in the original sample. Recovery of carbonate was checked by adding 4 mg. of sodium bicarbonate to 5 ml. aliquots of the diluted sample. The carbon dioxide was recovered quantitatively. Sulfite apparently does not interfere because no additional gas was evolved when 5 mg. of sodium sulfite was added to a 5 ml. aliquot of diluted sample or to 5 ml. of water.

None of the 12 molasses samples tested showed more than 0.07 percent carbonate and within the limits of accuracy of the method (0.07 percent) no carbonate was detected.

Acknowledgment

The authors thank officials of the beet sugar companies for the molasses samples and K. T. Williams of this Laboratory for devising the method used for carbon dioxide determinations.

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Plastic Protective Coatings

ALLAN WOODS[1]

Plastic coatings are being tried by Union Sugar Division, Consolidated Foods Corporation in place of the usual oil paints as a means of providing a more complete, durable coating that will fully resist corrosion. During the year 1955, coatings have been applied successfully to the continuous diffuser, Oliver filters, other internal equipment, and to a lesser extent on the buildings and other minor pieces of equipment. With the rising costs of labor and materials necessary to make yearly replacements in equipment due to corrosion and numerous paint failures, plastic coatings were tried as a means of controlling these losses. (1, 2)[2].

A careful survey of the available types of plastic materials was made and coatings were selected for trial primarily on the basis of their ability to withstand the corrosive effects of temperature and moisture. The next consideration was whether to determine if the material would stand both acid and alkaline corrosive agents. This latter requirement was first tested in the laboratory prior to application and subsequently in the field. In the laboratory tests, the materials were subjected to pure mineral reagents and in the field, the results of natural organic reagents present in the juices were observed.

In the application of plastic coatings to beet sugar equipment, it has been found that strict attention must be given to the conditions existing at the point of application. Generally speaking, when excessive moisture and heat conditions are present, in addition to the constantly changing acid and alkaline corrosive agents, extreme toughness and durability on the part of the plastic is required. Certain fundamental requirements had to be adhered to if satisfactory performance was to be obtained. These were: 1. Preparation of surface. 2. Adequate film thickness. 3. Selection of type of plastic material.

Preparation of Surface

The success or failure of any plastic coating starts with surface preparation (3). In instances where the coating is subjected to total immersion, the surface must be sandblasted to white metal. In no case has our company been able to hold a coating under these conditions without resorting to this procedure. Where the surface is exposed only occasionally to wetting or fumes, a thorough wiping and wire brushing of the corroded surface was sufficient. Other methods such as solvent cleaning,

[1] Factory Superintendent, Union Sugar Division, Consolidated Foods Corporation, Betteravia, California.

[2] Numbers in parentheses refer to references.

pickling, or flame cleaning are not advised. These have produced coating failures when tried.

Blast cleaning to white metal removes all mill scale, rust, spatter, flux, and other detrimental materials. A grit which polishes the surface must be avoided. In the trials here reported, steel slag for blasting has worked out very well and lends itself to repeated use after screening out the dirt and fine material. After blasting the surface is best cleaned with a vacuum cleaner, thus avoiding dusting and recontamination of the surface.

The initial or prime coat should be applied as soon as possible after the surface is prepared. In terms of practical application, this means within eight hours after the surface is sandblasted. Successive coats should be applied as quickly as the preceding coat is dry.

Adequate Film Thickness

If a surface is properly prepared, the protective value of the coating will largely depend on the thickness of the coating (4, 5). To a certain degree, surface coatings are not completely impermeable to moisture and gases and as the film thickness decreases, permeability increases disproportionately.

The surface tension of the liquid causes the coating to pull thin over the high points of sharp edges, welds, or seams and further causes the plastic to pile up excessively in the corners and crevices, usually entrapping air bubbles. Hence, the minimum thickness of the coating should be enough, that when measured on a plane surface, will give adequate protection at some lesser thickness over irregularities. It is generally recommended that a minimum thickness of 0.005 inch be applied. In most cases the average thickness obtained per coat is about 0.001 inch.

For severe conditions where the coating is subjected to total immersion, our company has adopted a uniform standard of not less than eight coats. Our experience has shown that with an application of less than six coats the surface fails rapidly and the additional two coats have been well worth applying.

Decisions governing the optimum coating thickness are influenced by the anticipated permanence of the equipment and the degree of importance of permanent 100 percent protection. In order to avoid difficulties arising from uneven application of repeated coats, different colors may be used. This method shows up weak spots as the coatings are applied or after the final application. It also shows defects due to cracking, peeling, or trapped air bubbles after the final coating is dry.

Table 1.—Coating Applications.

Type of Coatings	Application	Corrosive Agent	Operating Temperature	Condition of Coating (After 1 Yr.)
Straight Phenolic Resin	Diffuser Cell Walls	Raw Juice	160-190°F	Failure
Modified Phenolic-Epoxy Resin Coatings	Silver Diffuser Cell Walls	Raw Juice	160-170°F	Good
	Oliver Filters	Hydrochloric Acid	180°F	Good
	Evaporators	Thin Juice, Hydrochloric Acid, Sod. Hydroxide	200°F	Good
	Thick Juice Storage Tanks	Hot Thick Juice	195°F	Good
	Liquid Sugar Tanks	Hot Sugar Syrup	190°F	Good
	White Mixer	White Fillmass	200°F	*Failure
Vinyl Resin Coatings	White Mixer	White Fillmass	200°F	*Fair
	Wet Sugar Bin	Wet Sugar Moisture	180°F	Good
	Centrifugal Discharge Chutes	Wet Sugar and Steam	180°F	Good
	Silver Diffuser Cells	Raw Juice	160-170°F	Failure
	Liquid Sugar Filters	Hot Sugar Syrup	190°F	Good
Alkyd Resin Coating	Bldgs. and Outside of Equipment	Sugar Vapors, Acid and Alkaline Fumes	70-120°F	Good
Chlorinated Rubber Base Paints	Bldgs and Structural Steel	Sugar Vapors, Acid and Alkaline Fumes	70-120°F	Failure
Coal Tar Plastic Coatings	Cold Water Lines	Condensed Moisture	60-80°F	Good
Polyvinyl Acetate Coatings	Cover for Petroleum Base Coatings and Insulation Materials	Condensed Moisture	60-80°F	Good
Petroleum Resins Coatings	Temporary Protection of Process Equipment (Beet Washer, Elevator, Syrup Tanks, Catchalls, etc.)	Condensed Moisture	60-190°F	Good

* Condition due to insufficient coating thickness.

Selection of Plastic for Coating

The chief considerations advanced in selecting a plastic coating for a given application as previously referred to are: 1. Maximum temperature resistance required. 2. Type of corrosive agent present.

Table 1 shows the various types of plastic coatings used (6). A list of coatings applied successfully is as follows: Plastic No. 7155, Tygon TP61, Line Tite 700 coating, No Drip Plastic Coating, Nalcrete Polyvinyl Acetate Coating, and Sovakote No. 602.

For temperature ranges near or above the boiling point of water, Vinyl and epoxy-phenolic resin type coatings were chosen. For temperature conditions below 140° F., alkyd resin paints were used. Petroleum (7) and coal tar resin coatings were used at temperatures near or below the ambient temperature. Polyvinyl acetate water mixed resins were used to cover these latter coatings as they did not allow the under protecting material to bleed through and at the same time presented a good, clear, light-reflecting surface. The combination of the two types of resin coatings used in this manner avoids the usual objection to the use of petroleum plastics due to their black color and poor light reflectance. Vinyl coatings possess good resistance to the corrosive conditions encountered, but are extremely difficult to apply. The surface must be sandblasted or a special primer used to obtain the necessary adherence of the coating. Our company has adopted the procedure of taking both the precaution of sand blasting and using a single special primer coat. Coatings applied in this manner have given good service. Before this procedure was adopted a number of unexplained failures were encountered.

Phenolic resins have better adhesion but must be modified with other resins such as epoxy or furfural resins to provide the necessary acid resistance. Ordinary phenolic coatings, not compounded with other materials, failed where tried.

Petroleum resins were introduced primarily for temporary protection of equipment during intercampaign. One of these coatings exceeded all expectations and provided good protection in open syrup tanks at temperatures of approximately 200° F. Several types of these materials are available at a low initial cost and can be used effectively where temporary or semipermanent protection is desired without resorting to any special surface preparation.

Epoxy phenolic resin plastics (8) are not too difficult to apply and have given good service under extremely difficult conditions. These coatings have been exposed to organic acids in the battery and standard liquor tank, to mineral acids and alkalies

on the Oliver filters and evaporators for the past year without deteriorating to any extent.

The coated evaporator bodies were cleaned as frequently as once a week with dilute sodium hydroxide and hydrochloric acid solutions near the boiling point of water. The service rendered was of inestimable value especially when consideration is given to the fact that the bodies are more than fifty-five years old and the original cast iron has degraded to the point where it would no longer stand up under the necessary boilout procedures.

These plastics have also been used to coat the inside of the liquid sugar melter and storage tanks and have given good service in this instance. Some difficulty has been experienced with the welds that were not ground smooth before coating necessitating patchwork at these points. In general the coatings have proven very satisfactory.

Chlorinated rubber base coatings have given disappointing results where tried. This type of coatings has been replaced on structural steel and factory equipment by Alkyd resin coatings which are much cheaper and have resisted corrosive action comparatively longer.

Summarizing the results and experiences with plastic coatings, our company is well satisfied that plastic-type materials have an important place in the sugar industry and that their use will continue to grow and develop as new materials are provided. Success with the epoxy-phenolic type resin coatings has been satisfying and plans are to use this type of plastic extensively to control corrosion in the continuous diffuser, the evaporators, throughout the beet end, the sugar end, and wherever corrosion or rust endanger the final product and necessitate costly yearly replacement.

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Sugar Beet Infection by More Than One Strain of Curly-Top Virus

N. J. GIDDINGS[1]

Introduction and Methods

These experiments were undertaken as an extension of earlier studies by Giddings (3, 4)[2] and include curly-top virus strains that were not available during the earlier work. Plants grown from curly-top susceptible sugar beet roots 2 to 3 inches in diameter were used for the maintenance of all virus cultures. Such plants are designated as source plants. Approximately 30 adult leafhoppers or 50 nymphs were used in making each of the original transfers to source plants and up to 50 leafhoppers or nymphs, according to numbers available, were used for subsequent transfers. To assure infection by both strains of a combination, the future source plant was first inoculated by the less virulent curly-top virus strain, or by one that it was hoped might be suppressed, and some days later, by the second strain of the combination.

Small, usually two-leaf, susceptible and/or resistant seedling sugar beet plants were used in making tests from either single strains or combinations of the strains. Final readings of symptom severity and/or mortality were usually made about six weeks after inoculation.

The severity of grade of symptoms is based on a scale of 5 points with non-infection indicated by 0.0.

Fourteen virus strain combinations were used, eight of which had not been tested before.

Results and Discussion

Table 1 gives the results from four virus strain combinations that had not been previously reported. The original, single-strain colonies, listed in Table 1, had been maintained for several years and no date for the original source plant inoculations is given. The first date given in the left-hand column shows when the first of the two-combination virus strains was inoculated into the source plant; the second virus strain inoculation was made on the second date.

The data given in Table 1 deals only with severity of symptoms and mortality of test plants. The percentage of plants infected is a factor that seems unnecessary to include. Strains 7 and 3 rarely infect the highly resistant sugar beet and any such plants infected show very mild symptoms. Susceptible beet plants infected

[1] Collaborator (formerly Senior Pathologist), Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Riverside, California.

[2] Numbers in parentheses refer to literature cited.

Table 1.—Results of Tests from Large, Susceptible Sugar Beet Plants Infected by Curly-top Virus Strain Combinations, Showing Severity of Symptoms and Mortality of Susceptible Test Plants and Severity of Symptoms of Resistant Test Plants.

Dates of First Transfer to Source Plant		Virus Strains Used	Test Dates 1954 Aug.	1955 Feb.	1955 May	1955 July	1955 Nov.	1956 Mar.	1956 June
A. Results on Susceptible Test Plants									
			Average Symptom Severity						
		7	1.1	1.3	0.9	0.5	2.1	2.3	1.8
		2	2.0	1.8	2.0	1.4	1.1	1.2	1.6
		3	5.0	3.6	4.1	4.4	3.5	3.3	3.5
1/22	2/2/55	7 + 11		5.0	4.7	5.0	4.8	4.6	4.8
1/22	2/2	2 + 11		4.7	5.0	4.0	4.9	4.9	4.8
1/26	2/2	3 + 11		4.7	4.9	4.4	5.0	5.0	4.7
		11	5.0	4.5	4.7	5.0	5.0	5.0	4.9
		3	5.0	3.6	4.1	4.4	3.5	3.3	3.5
2/2	2/26	3 + 12		....	3.0	4.3	2.5	3.0	2.9
		12	3.5	3.1	2.9	3.4	1.9	2.3	1.5
			Percent Mortality After Approximately Six Weeks						
		11	75	33	73	64	18	14	60
		7 + 11		27	50	37	27	20	50
		2 + 11		42	73	56	33	18	40
		3 + 11		25	42	100	20	37	67
B. Results on Resistant Test Plants									
			Average Symptom Severity						
		7	0.0	0.0	0.0	0.0	0.0	0.0	1.0
		2	0.9	0.7	0.8	0.7	1.1	0.7	1.3
		3	0.0	0.0	0.0	0.0	0.0	0.0	1.0
1/22	2/2/55	7 + 11		2.7	3.4	4.8	4.3	3.4	4.6
1/22	2/2	2 + 11		3.8	3.3	3.4	4.7	4.9	4.4
1/26	2/2	3 + 11		2.6	2.7	3.5	4.3	4.6	4.0
		11	3.4	4.5	3.6	3.0	4.9	5.0	3.1
		3	0.0	0.0	0.0	0.0	0.0	0.0	1.0
2/2	2/26	3 + 12		....	2.0	1.5	....	0.0	1.0
		12	1.0	0.0	0.0	1.8	0.0	1.0	1.0

by strain 7 show very mild symptoms while similar plants infected by strain 3 show severe symptoms. Strains 2 and 11 readily infect both susceptible and resistant test plants but strain 2 induces mild symptoms while strain 11 induces very severe symptoms, with a high mortality among susceptible plants and severe symptoms in the resistant beets. Strain 12 induces a different type of symptom than the others mentioned and is relatively mild on both susceptible and resistant beets with a comparatively low rate of infection among the resistant plants.

Considerable variation is evident in the severity of symptoms recorded at different test dates. Such variations apply to the

plants infected with the original single virus strains as well as to those infected by the two-strain combinations. These variations are largely accounted for by differences in the environmental conditions at the times of the tests, age and size of test plants, and differences in the genetic character of the test plants.

It was necessary to change the variety of both susceptible and resistant test plants during the period of the experiment. Larger numbers of test plants would also have tended to smooth out some of he differences indicated in severity between different test dates. Symptom severity variations are well illustrated in Table 1 and Figure 2 of an earlier publication (2, pp. 886-887 and 890). The percentage mortality is given for only those strain combinations in which a significant number of the susceptible test plants died.

It is interesting to note that infection by a combination of 2 virus strains does not seem to induce greater symptom severity than infection by the single, more-virulent strain of the combination. Similar evidence was obtained from some other experiments, although an earlier report by Giddings (1) suggested that there appeared to be greater severity from the combined infections.

Summary

Some new combinations of curly-top strains were tested on large, susceptible sugar beet plants. Plants infected by one strain of the virus were readily infected by a second strain. Young test plants inoculated from such sources gave no indication that the earlier infection of the source plant by one curly-top virus strain tended to significantly reduce the virulence or change the character of either virus strain after infection by a second, more virulent strain, or a strain inducing characteristically different symptoms.

The environmental conditions and host relationships that might induce mutations of this virus should have further study.

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Correlation Studies of Chemical and Morphological Characters of Sugar Beet Variety GW 413

ERNST ARTSCHWAGER AND H. E. BREWBAKER[1]

The purpose of this study was to determine the extent of any inherent association between the internal morphology and certain important chemical characters in a variety of sugar beets known to be genetically heterogeneous, from which the value of any such relationship as an aid in selection might be judged.

The material used consisted of roots selected at Billings, Montana, from GW 413, a genetically heterogeneous variety developed from a cross of two unrelated varieties followed by several generations of family selection. The roots used represented approximately the upper half of the population based on size of root with minor attention being given to appearance. For this reason, the correlation study may have particular interest to the beet breeder since he is concerned chiefly with this part of any segregating population.

The chemical characters used in this investigation included sodium and raffinose in addition to sugar and purity. Sodium and raffinose are of interest since they interfere with efficient extraction of sucrose and since both have been known to be negatively associated with sucrose.

For the evaluation of the internal morphology the type formula was employed (2, 3).[2] In addition, structural peculiarities, color and texture of flesh, number of rings, ring density coefficient, and size of central core are recorded.

List of Characters Used in the Construction of the Type Formula

General appearance of the cut surface *in situ*

1. Surface mealy white; zonation faint.
2. Zonation indicated.
3. Zonation pronounced; flesh often gray and translucent.

Appearance of thin cross section in water against black background

4. Zonation indicated.
5. Zonation pronounced; rings distinctly set off from interzonal parenchyma.
6. Rings very prominent with limits of phloem and xylem clearly defined.

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[1] Botanist, Field Crops Research Branch, Agricultural Research Service, U. S. Department of Agriculture and Director, Agricultural Experiment Station, The Great Western Sugar Company, respectively.

[2] Numbers in parentheses refer to literature cited.

Width of vascular rings

7. Rings broad.
8. Rings narrow.
9. Rings variable; inner rings characteristically broader.

Width of interzonal parenchyma

10. Parenchyma bands broad.
11. Parenchyma bands narrow.
12. Parenchyma bands of inner rings conspicuously broader.

Size of first ring

13. Rings broad with a diameter of 22 mm. or more.
14. Rings medium large.
15. Rings narrow with a diameter of 12 mm. or less.

Morphological and chemical data for roots are given in Table 1, and the correlations for some of the characters in Table 2.

Table 1.—Chemical and Morphological Data on 116 roots of Variety GW 413.

Root No.	Weight	Sucrose %	Sodium	Raffinose	Purity	Core Mm.	1st Ring Mm.	Ring Nos.	R.D. Coeff.	Type Formula
1	6.2	14.9	0.030	1.6	95.4	6	25	12	2.0	3-6-7-11-13
2	4.6	17.8	0.020	1.4	96.8	5	25	11	2.0	3-6-7-11-13
3	7.4	16.7	0.025	1.25	95.6	8	35	9	1.5	3-6-7-11-13
4	4.3	16.6	0.039	0.95	96.2	5	25	11	1.8	3-6-7-11-13
5	5.4	14.7	0.065	1.55	95.2	6	30	10	1.7	3-6-7-12-13
6	4.1	14.5	0.032	1.35	94.3	5	28	8	1.6	2-5/6-7/8-12-13
7	5.2	15.3	0.050	0.9	92.6	7	28	10	1.8	2-4/5-7-12-13
8	6.8	15.1	0.066	1.2	95.8	6	30	10	1.5	3-6-7-11-13
9	3.9	16.8	0.035	1.43	98.2	7	28	9	1.8	2-5/6-7-11-13
10	5.5	16.5	0.035	1.30	97.5	10	35	9	1.6	2-5-7-12-13
11	5.2	17.0	0.045	0.60	96.00	8	30	10	1.6	2-5/6-7-11-13
12	4.2	17.4	0.045	1.20	95.9	7	27	10	1.7	2-5-7-12-13
13	4.7	15.5	0.038	1.10	95.4	4	30	9	1.9	2-5-8-10-13
14	3.8	16.5	0.021	1.40	97.2	7	30	9	1.6	3-5-7-11-13
15	6.4	15.1	0.090	0.60	93.6	6	30	10	1.6	3-6-7-12-13
16	4.6	16.4	0.028	1.00	94.3	8	27	8	1.6	3-6-7-11-13
17	4.4	15.7	0.030	0.50	95.0	6	27	10	1.6	2-6-7-11-13
18	4.0	16.2	0.032	1.20	96.0	4	25	12	2.4	2-6-7/8-10-13
19	6.1	16.3	0.036	1.80	97.4	10	32	9	1.6	2-5/6-7-11-13
20	5.4	14.6	0.067	1.25	94.7	7	30	9	1.6	1-4-7/8-10-13
21	4.3	16.1	0.047	1.10	95.7	8	30	9	1.6	1/2-4-7-12-13
22	3.6	16.9	0.028	1.55	98.0	6	23	13	2.6	3-6-8-11-13
23	6.3	15.7	0.038	0.85	94.9	7	30	10	1.8	2-6-7-11-13
24	5.3	17 7	0.016	0.98	96.4	5	21	12	2.2	3-6-7-11/12-14
25	3.9	16.7	0.025	0.90	97.0	3	22	11	2.2	2-6-8-10-14
26	4.9	16.1	0.022	1.40	97.8	8	28	9	1.8	2-5-7-10/11-13
27	6.8	16.6	0.045	0.90	95.8	6	30	9	1.5	2-4-7-10-13
28	3.8	15.5	0.048	0.83	96.8	6	28	9	1.6	2-5-8-10-13
29	4.3	17.2	0.030	1.50	96.3	7	30	12	2.2	3-6-7-11-13
30	5.4	15.6	0.028	1.08	96.4	10	32	10	1.8	2-5/6-7-12-13
31	6.3	16.1	0.030	1.05	95.8	4	25	10	1.6	1/2-5-7-11-13
32	4.6	17.3	0.016	1.20	97.6	8	33	11	2.0	1/2-5-7/8-12-13
33	4.3	17.6	0.017	0.85	98.3	6	28	10	2.1	2-5-7-12-13
34	4.1	17.5	0.022	0.55	96.4	5	28	12	2.4	2-5-7/8-12-13

Table 1. (Cont.)

Root No.	Weight	Sucrose %	Sodium	Raffinose	Purity	Core Mm.	1st Ring Mm.	Ring Nos.	R.D. Coeff.	Type Formula
35	4.8	15.7	0.027	1.05	95.6	5	28	9	1.8	2-5-7/8-12-13
36	3.7	17.3	0.021	0.63	93.8	2	13	9	1.8	1-5-8-10-14
37	4.6	16.7	0.048	1.10	98.5	8	30	8	1.5	2-4/5-7-10-13
38	4.7	17.9	0.018	0.80	97.8	4	24	12	2.0	1-5-7/8-12-13
39	3.8	16.7	0.018	1.15	96.5	6	30	11	2.2	3-6-7-12-13
40	2.7	16.9	0.026	0.90	98.3	7	25	9	1.8	2-5-7-10-13
41	2.0	15.3	0.065	1.20	94.4	8	32	9	2.1	2-6-8-12-13
42	2.2	15.5	0.040	1.50	96.4	4	24	10	1.8	1-4/5-7/8-12-13
43	3.9	17.6	0.018	0.85	97.2	8	32	10	1.7	1-4/5-7/8-12-13
44	3.3	18.6	0.015	0.60	95.2	5	25	9	1.8	2-6-7-12-13
45	2.6	16.6	0.028	1.45	96.1	6	32	9	1.8	1-4-8-10-13
46	2.2	15.5	0.032	0.70	94.8	5	28	8	1.6	2-6-7-10/11-13
47	2.2	16.0	0.032	1.33	97.0	10	34	8	1.4	2-5-7/8-12-13
48	3.1	16.6	0.043	0.95	96.3	7	27	9	1.6	1/2-4-7-12-13
49	3.7	15.9	0.046	0.85	95.1	6	28	10	1.9	2-5-7/8-12-13
50	2.4	16.6	0.022	1.15	95.1	6	27	11	2.2	3-6-7-12/11-13
51	3.0	17.1	0.020	1.0	97.2	6	25	11	2.0	2/3-5/6-7-12-13
52	2.9	16.3	0.052	0.90	95.9	8	35	12	2.0	3-6-7-11-13
53	3.2	16.3	0.044	0.85	95.4	6	25	10	1.8	2-5-7/8-12-13
54	2.8	18.4	0.019	0.95	97.3	6	33	8	1.6	2-6-7-12-13
55	2.9	17.6	0.029	1.00	96.8	8	34	9	1.6	3-6-7/8-10-13
56	3.5	16.3	0.025	0.83	96.4	5	30	11	2.0	2-5-7/8-12-13
57	3.9	17.5	0.017	0.60	95.4	3	20	11	1.9	3-6-7-11-14
58	2.5	17.5	0.026	1.20	95.2	5	28	10	2.0	3-6-7/8-10-13
59	3.4	17.4	0.034	0.60	96.3	6	28	10	1.85	1-4/5-7-12-13
60	3.0	16.7	0.032	1.15	97.0	8	33	10	1.5	2/3-5/6-7-12-13
61	2.0	17.5	0.022	1.05	93.7	4	23	11	2.2	2-5-8-12-13
62	2.7	13.0	0.013	0.90	97.2	8	30	9	1.5	2-5/6-7-12-13
63	1.8	15.0	0.026	0.90	95.7	7	29	9	2.0	2-5-8/7-12-13
64	2.1	16.4	0.024	0.90	97.9	7	25	8	1.8	2-6-8-12-13
65	2.8	15.7	0.018	1.70	99.8	6	22	10	2.0	2-5-7-10-14
66	2.9	16.4	0.022	1.05	97.8	7	27	12	2.0	1-4-7-12-13
67	3.4	16.2	0.021	1.70	97.8	6	30	10	1.8	1-5-7/8-12-13
68	3.2	17.7	0.015	1.30	98.4	5	25	10	2.1	2-6-7/8-12-13
69	2.6	14.6	0.041	1.25	94.9	6	26	10	1.8	2-5-7/8-12-13
70	2.4	16.4	0.019	1.00	96.7	7	27	10	1.8	1-4-8-10-13
71	3.6	15.0	0.032	1.75	96.2	7	28	8	1.3	3-6-7-12-13
72	3.0	16.3	0.021	1.65	96.2	7	22	12	2.2	1-5-8-12-14
73	3.2	14.9	0.048	1.60	93.2	5	26	11	2.0	2-5-7/8-12-13
74	4.6	16.6	0.050	0.95	96.0	8	33	8	1.3	1-4-7-12-13
75	2.8	16.3	0.038	0.78	95.7	5	28	11	2.2	3-6-7-12-13
76	2.7	15.5	0.043	1.25	96.6	6	24	12	2.2	2-5-8-12-13
77	3.4	15.1	0.046	1.60	94.7	5	23	10	1.85	3-6-7-11-13
78	2.3	16.2	0.018	1.28	95.8	4	23	11	1.85	1-4/5-8-10-13
79	3.4	15.3	0.031	1.70	96.5	7	30	12	1.9	2-6-7-12-13
80	2.4	14.9	0.086	0.70	92.8	4	27	7	1.2	2-5-7-12-13
81	4.0	15.4	0.028	1.60	97.5	5	27	9	1.5	2/3-5/6-7-11-13
82	3.7	14.0	0.060	1.40	94.9	6	30	9	1.4	2-5/6-7-12-13
83	2.9	14.6	0.044	0.48	95.5	9	35	11	2.2	2-6-8-12-13
84	2.4	16.3	0.032	1.65	98.2	6	28	9	2.0	2-5-7/8-12-13
85	2.8	17.3	0.096	1.80	99.2	3	25	11	2.0	1-4-8-10-13
86	3.3	17.3	0.032	0.60	94.8	3	21	11	1.85	1/2-5-7/8-12-14
87	3.8	14.4	0.045	1.53	94.3	3	25	11	1.85	2-6-7-12-13
88	3.5	16.8	0.036	0.60	96.9	3	25	9	1.5	2-5-7-12-13
89	2.4	13.9	0.056	0.70	93.3	3	26	9	1.8	2/3-5-7/8-10-13
90	3.7	15.6	0.023	1.28	95.2	9	35	9	1.8	3-6-7-11-13

Table 1. (Cont.)

Root No.	Weight	Sucrose %	Sodium	Raffinose	Purity	Core Mm.	1st Ring Mm.	Ring Nos.	R.D. Coeff.	Type Formula
91	2.3	15.6	0.013	0.95	96.0	5	25	8	1.75	2/3-5/6-7-11-13
92	3.4	14.5	0.029	0.75	94.5	7	28	9	1.5	2-5-7-12-13
93	2.4	16.1	0.020	1.35	97.2	4	19	12	2.2	1-4/5-7/8-12-14
94	3.3	15.1	0.029	0.90	97.7	4	22	11	2.0	2-5-7/8-12-14
95	3.7	12.2	0.085	1.65	97.9	3	33	8	1.4	2/3-5/6-7-12-13
96	3.4	15.8	0.019	0.70	98.9	6	27	10	2.0	2-5-7-12-13
97	3.1	13.2	0.035	0.65	95.3	5	25	9	1.65	3-6-7-12-13
98	3.1	13.6	0.051	1.20	95.7	10	35	9	1.8	3-6-7-11-13
99	3.4	18.2	0.021	1.15	94.1	5	21	10	1.8	3-6-7-11-14
100	3.0	16.6	0.043	1.80	95.4	5	27	9	1.6	3-6-7-12-13
101	1.8	16.8	0.027	1.10	97.5	6	25	10	2.0	2-5-8-10-13
102	2.0	18.7	0.017	0.50	97.1	6	26	10	2.0	1/2-4-8-10-13
103	3.4	14.7	0.018	1.30	92.1	5	32	9	1.5	1/2-4/5-7-11-13
104	2.3	16.6	0.050	0.93	93.3	5	26	9	2.0	1/2-4-7/8-12-13
105	6.9	14.5	0.023	1.20	92.9	9	40	9	1.5	3-6-7-12-13
106	5.0	15.1	0.071	1.10	94.3	6	25	14	2.2	2-5-7-12-13
107	2.4	17.2	0.042	1.20	97.8	10	30	10	1.8	2/3-6-7-12-13
108	3.0	17.3	0.018	0.55	96.9	8	34	9	1.8	1-4-8-10-13
109	2.1	18.4	0.014	0.85	91.3	6	26	11	2.1	1-4-7/8-12-13
110	4.4	17.2	0.034	1.10	95.0	9	34	10	1.7	3-6-7-11-13
111	1.9	17.7	0.019	1.30	97.3	6	27	8	1.75	2-5-8-12-13
112	4.3	17.2	0.019	0.70	93.9	6	30	10	1.8	2-6-7-12-13
113	3.5	17.2	0.025	0.70	95.4	3	17	12	2.2	2-5-8-12-14
114	3.4	16.8	0.016	1.33	94.8	5	27	11	1.85	1-5-7-12-13
115	3.5	17.9	0.017	0.55	96.4	6	24	9	1.8	2-6-7-11-13
116	2.5	17.9	0.017	0.80	96.4	4	24	9	1.8	2-6-7-11-13

Table 2.—Correlation Coefficients for Characters Observed on 116 Roots of Variety GW 413.

	2	3	4	5	6	7	8	9
Characters	% Sucrose	Sodium	Purity	Raffinose	Core	1st Ring	Ring Nos.	Ring density coefficient
Weight	—.10	.15	—.09	.05	.18	.26	.04	—.24
% sucrose		—.52	.37	—.31	—.06	—.24	.19	.22
Sodium			—.50	.28	—.04	.22	—.14	—.30
Purity				.11	—.32	—.06	.11	.20
Raffinose					.11	.10	.05	—.01
Core						.70	—.26	—.22
1st Ring							—.34	—.39
Ring Nos.								.76

r = .18 for sig. at 5% point.

Correlation Considerations

While the internal structure of the beet root as represented by the type formula and certain subsidiary characters is constant for a pure line (2) and can be used by the breeder for diagnostic purposes, the roots of variety GW 413 exhibited a great diversity of types (Figures 1 and 2). However, certain character combinations were occasionally recurring (Table 1), so that the roots could be grouped into classes of from 2 to 14 individuals.

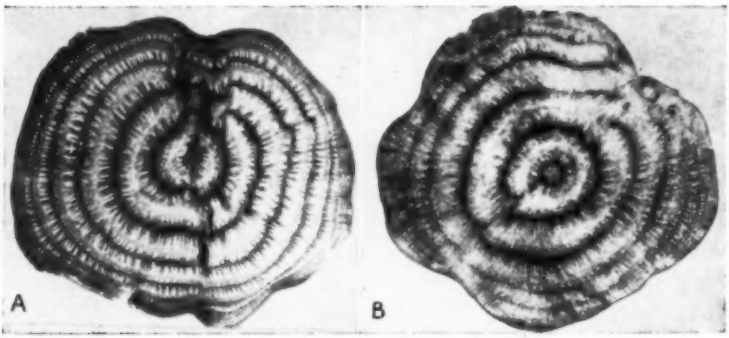

Figure 1.—*A* Root No. 77. Uniform ivory-cream flesh with very prominent bundles. Type formula 3-6-7-11-13. *B* Root No. 48. Light cream-colored flesh with long fading bundles. Type formula 1/2-4-7-12-13.

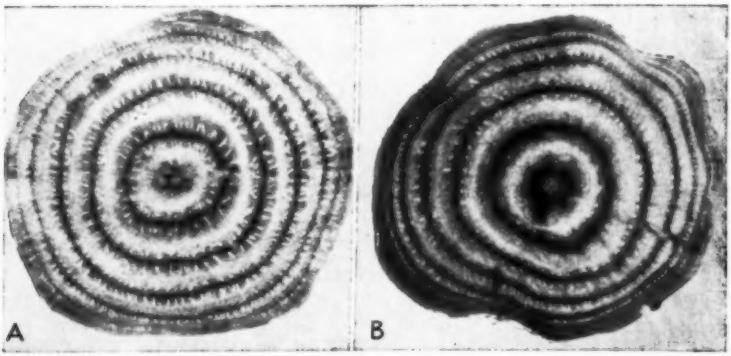

Figure 2.—*A* Root No. 13. Broad white bundle zones and somewhat watery parenchyma bands; small compact core. Type formula 2-5-8-10-13. *B* Root No. 108. Gray watery flesh with fading bundles, large compact core. Type formula 1-4-8-10-13.

Association studies showed no correlation between the different anatomical characters except that of the size of the central core with the diameter of the first ring and of the number of rings with the ring density coefficient.

As compared with previous studies using inbred lines (3), the results obtained in this investigation for chemical characters agree rather well, particularly for the negative relationship of sucrose with sodium and raffinose, and sodium with purity. Also, the absence of any significant effect of raffinose on purity for this material confirms the results with inbred lines. The obtained r value of .37 for sugar with purity (Table 2) is somewhat lower than expected, a corresponding value of .68 having been obtained for inbred lines (3).

The fact that the beets studied represented the upper half of the population based on size might conceivably change the size of some of the r values. For example, Pack (4) obtained an r value for weight with ring density of $-.641 \pm .018$, whereas here the value obtained for the same relationship was $-.24$ with a required r value of .18 for significance at the 5 percent point.

Rusconi-Camerini (5) obtained a significant negative correlation between ring density and weight and a positive correlation between ring density and sucrose, but with the values varying in the E and Z types. These data are in agreement with those in Table 2.

Table 3.—Correlation Coefficient for Ring Density with Other Characters.

Character	Pack	Artschwager and Brewbaker
Weight of beet	$-.641 \pm .018$	$-.24$
% sucrose	$.300 \pm .028$	.22
Purity	$.125 \pm .030$	.20

Summary and Conclusions

The roots used for this study were representative of the upper half, based on size, of a heterogeneous population of sugar beets. Any effective or sizeable correlation between easily observable anatomical characters and important though less easily obtained chemical characteristics could be of real value to the plant breeder. The obtained r value of .22 for ring density with percent sucrose and .20 for ring density with purity obtained in this study, while significant at the 5% level, are hardly sufficient to encourage the use of ring density as a short cut to improvement by selection for these characters.

Probably the principal value to be attached to these anatomical characters is in connection with their use as identifying characteristics of uniform strains, especially pure lines. Such pure lines differ very greatly in these respects and the fact that roots and lines can be catalogued accurately for these characters has been demonstrated in these and previous studies referred to in this paper.

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Sugar Beet Stand Studies

E. G. Eckroth and C. E. Cormany[1]

Introduction

A definite association between after-thinning stands and yield of sugar beets should be stressed in any beet growing area, particularly in northern growing regions. Some uncertainty exists as to what makes up the most desirable stand. There are still some growers who instruct their labor to space the beets more than a foot apart, with many 65 percent stands resulting.

The normal growing season in this northern area is very definitely limited. The Sidney, Montana, factory records show that in 1953 there were 130 frost free days; in 1954, 119 days; and in 1955, 154 days. The long daylight hours experienced during the middle of summer, however, do partially make up for the shorter growing season. Due to the shorter season, it is all the more important that an optimum stand be maintained and every day of the growing period utilized.

Doxtator and Skuderna (1)[2] obtained evidence from tests conducted in widely separated areas that yields of sugar beets can be increased by thinning to higher acre populations of beets. Frakes (2) found no significant differences in yield of sugar beets when spacings of 10, 12, 16 and 20 inches were used.

Procedure

During each of the past three years, sixty farms of the Sidney, Montana, district were checked for yield, final stands, and other data. Only the association between yield and stand will be discussed in this report.

Ten stand counts per field were made with the assistance of the fieldman in each district. In addition, stand tests were conducted in experimental plots during these three years and will be included in this report.

Results and Discussion

Table 1 illustrates very well the definite correlation between stand and yield.

It is interesting to note that as the stand improves, the yield increases. The average stand for the 60 farms was 77 percent or 77 beets per 100 feet of row in 1953, 78 in 1954, and 82 in 1955. The stands in the commercial fields need improving. Table 1 shows a difference of about 4 tons between a 90 percent stand and a 65 percent stand. A 65 percent stand during a short sea-

[1] Associate Agronomist, Holly Sugar Corporation, Sidney, Montana; Chief Agronomist, Holly Sugar Corporation, Sheridan, Wyoming, respectively.

[2] Numbers in parentheses refer to literature cited.

son cannot be expected to yield as high as a 90 percent stand. The 25 percent difference in stand is often too much to make up and even where the season is long, only a part of the difference can be made up. One must have a maximum stand to insure a maximum yield.

To further supplement this summary, controlled stand tests were conducted during the same three years. The results of these tests as shown in Table 2 also demonstrate the importance of a good stand.

In 1953 and 1954 the average stands of 100 to 80 beets per 100 feet of row are significantly higher than a stand of 60 beets in tons and gross sugar per acre. The association is obvious and the importance of a good stand cannot be over emphasized. The

Table 1.—Influence of Stands of Sugar Beets on Yield on 60 Eastern Montana Farms.

	Yield in Tons per Acre						
	Beets per 100 Feet of Row						
Year	95-100	90-94	85-89	80-84	75-79	70-74	65-69
1953	16.63	15.25	15.15	14.11	13.44	12.79	11.65
1954	16.75	15.40	14.68	13.92	12.52	11.82	10.74
1955	18.33	17.17	17.01	17.16	15.88	15.50	13.22
Average 3 years	17.25	15.94	15.61	15.06	13.95	13.37	11.87

Table 2.—Effect of Controlled Stands of Sugar Beets on Harvest Performance.

	Number of Beets in 100 Feet of Row[1]						
Year	110	100	90	80	70	60	LSD 5%
Tons/Acre							
1953	.....	13.07	12.61	12.15	11.89	10.78	1.23
1954	17.16	17.11	17.15	16.85	15.89	14.19	1.99
1955	17.33	17.53	17.09	16.55	16.30	15.91	NS
Gross Sugar/Acre							
1953	.....	4352	4207	4203	4028	3626	434
1954	5881	5890	5816	5726	5390	4805	694
1955	4826	4887	4757	4601	4503	4375	NS
Percent Sucrose							
1953	.....	16.65	16.83	17.05	16.98	16.83	NS
1954	17.15	17.21	16.97	17.04	16.98	16.94	NS
1955	13.92	13.94	13.92	13.90	13.81	13.75	NS

[1] Rows 22 inches apart.

1955 yield for the entire Sidney district was the second highest in its history. The differences in 1955, although not significant, are still present and illustrate the value of a good stand.

Sucrose percent during these three years was at no time affected by stand differences.

To insure better final stands, considerable study must be given the pre-thinned stands. This applies for both mechanical thinning as well as for hand thinning. On fields to be mechanically thinned, a careful study of pre-thinned stands must be made in order to determine the proper procedure with the thinning equipment to be used. Where hand labor is used, supervision of the thinning is an absolute necessity. All too often the beet crop in this region is made or ruined at thinning time.

What can be done about improving the final stands in eastern Montana? A number of things should be done: namely, (a) good seedbed preparation; (b) plant sufficient seed—about six to eight pounds per acre, and not more than an inch deep in heavy soil; (c) drive the tractor slowly while planting; (d) follow good cultural practices with the accent on timeliness; (e) maintain high fertility; (f) give a good cultivation just prior to thinning; (g) supervise the labor; (h) aim for at least 100 beets per 100 feet of row so that after reductions by diseases, insects, and weather, a good stand still remains; (i) make a careful application of water where necessary to irrigate for germination. Throughout the growing season keep the fields at optimum moisture condition for plant growth as the growing season is limited and every day is vital and should be properly utilized.

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Reloading of Beet Storage Piles in Alberta, Canada

RAY B. EVANSON AND WESLEY G. SMITH[1]

The three factories operated by Canadian Sugar Factories Limited, are situated at Raymond, Picture Butte, and Taber, Alberta. An annual production of approximately 430,000 tons is received at sixteen separate locations with distribution as follows:

	Tons
Piles at three factory points—subsequently rehandled	210,000
Piled at six country points—subsequently reloaded	100,000
Received and cut direct from field	120,000
	430,000

Of the three types of machines presently used to recover beets from storage piles are three crawler cranes, two hydraulic overshot loaders, and one hydraulic front-end loader. One of the crawler cranes is a P. and H. and two are Northwests; one of the hydraulic overshot loaders is on a D7 Caterpillar and one on a D8 Caterpillar. The hydraulic front-end loader is a Wagner LD20 Scoopmobile. The crawler cranes are now used only at factory points where shifts are required. The D7, D8, and LD20 reload country piles where 12- to 14-hour shifts handle the recovery.

The reloading program is influenced to some extent by the railway service. Switching, often only once or twice a day, has imposed the use of spur tracks designed to accommodate twenty 55-ton cars. One "clean up" man gleans beets, bills cars, and acts as a general assistant to the machine operator.

In our climate (often 10° to 20° below zero F.) reloading equipment must be designed to withstand rough treatment under low temperatures. Machines operate without incident as long as the weather is fine but troubles increase when the temperature falls below zero.

Crawler Crane

Crawler cranes with clamshell buckets holding approximately one ton are used to recover the majority of beets at factory points. Three such machines handle about 174,000 tons each year at a rate similar to that of the factory slicing capacity. They are very effective working against a frozen pile face; piles occasionally freeze to a depth of 20 to 30 feet. They operate smoothly under most conditions but lack mobility. Economical recovery is limited

[1] Factory Agricultural Superintendent and Agronomist, respectively, Canadian Sugar Factories Limited, Taber, Alberta, Canada.

to the boom swing. The bucket crushes and slices some beets which increases pile shrinkage. Major repairs are relatively infrequent. For a number of years, before overhead loaders were available, crawler cranes were used to reload country storage piles.

Overhead Loaders

A D7 Caterpillar tractor equipped with an overshot Athey loader was purchased in 1943. Mechanical breakdowns were numerous and maintenance costs were high. The heavy roller attached to the front of the Caterpillar crushed many beets as the machine went into the pile for a load. This roller also caused the Caterpillar frame to crack.

The Athey unit was abandoned after four campaigns and replaced by a hydraulic overshot loader designed and custom built by Curtis Hoover Limited, Edmonton, Alberta. Several difficulties were experienced during the first fall campaign. Piston rubbers failed, side-arm pins and master links were weak, and the balance wheel retained from the Athey was still smashing beets and causing stress cracks on the tractor frame. These conditions were corrected by using a superior quality rubber, enlarging side-arm pins, reinforcing master links, reducing bucket capacities and by the installation of bucket-tipping cylinders allowing lift arms to be shortened and the balance wheel junked.

On the basis of our experience with the D7, a D8 was purchased during 1948 and equipped with similar but heavier hydraulic attachments. Both machines are still in service.

Front-End Loader

An LD20 Scoopmobile was purchased during the fall of 1954 from Mixermobile Manufacturers Incorporated, Portland, Oregon. The Scoopmobile is a custom-built front-end loader powered by a Waukesha motor, which drives for pneumatic rubber-tired wheels. With a ten-yard scoop and travelling 100 feet from the pile to the railway cars, the Scoopmobile can handle approximately 200 tons of beets per hour.

The LD20 handled about 65,000 tons of beets each fall during 1954 and 1955, most of which were from country storage piles. On one of the initial demonstrations, a mixermobile operated by an experienced man and travelling approximately 50 feet under ideal conditions, loaded eight 55-ton railway cars or about 440 tons in one hour. Our operators handle an average of 200 tons of beets per hour carrying them about 100 feet from pile to car. This rate can be exceeded for short periods.

Mechanical difficulties with the planetary wheel drives, the bucket stabilizer piston rods, and the selector valve of the hydraulic system have resulted in major delays. Most of these problems have been corrected, but a few further adjustments are necessary. To cope with our severely cold weather conditions, we may find it necessary to replace the electrical starting system with a gasoline motor.

Costs

The costs of operation and maintenance are presented in Table 1. Interest and depreciation are omitted because these costs vary greatly with the tonnage handled and the life expectancy of the machine. Because the machine is relatively new, the cost of annual maintenance on the LD20 is low.

Table 1.—1954 Tonnage Handled and Cost per Ton and Maintaining Four Beet-Recovery Units in Alberta.

	D7	D8	LD20	Taber Crawler Crane
Tons loaded	40,000	31,000	65,000	71,288
Tons loaded per hour	122	135	200	92
Cost per ton				
Maintenance	.0442*	.0579*	.0157	.0617*
Operating (labor and material)	.0462	.0452	.0362	.0358
Total	.0904	.1031	.0519	.0975

* Average of three years, 1952—1953—1954.

Conclusions

The crawler crane will continue to be used to recover the majority of piled beets at factory points. With the crawler crane the piling ground maintenance costs are greater than those of the LD20; the costs were less with the crawler crane than with the D7 and D8 equipment.

The hydraulic overshot equipment, now mounted on the D7 and D8 Caterpillar tractors, has been strengthened and altered in some respects from the original design. This equipment performs an essential service in the reloading program, but in the near future, may be replaced by rubber-mounted units. The crushing of beets by the Caterpillar tracks is appreciable but largely unavoidable and must be accepted as part of this system of

handling. Bucket teeth are designed to eliminate digging but if the operator is careless or the grounds uneven, excess dirt will be loaded, thus, increasing freight and processing costs.

The LD20, highly maneuverable and reasonably economical to operate, is well adapted to reload country storage piles. A bucket discharge height of 14 feet was necessary due to the height of the railway car used, which was 12½ feet from the ground level to the top. A smaller Scoopmobile unit, geared to factory slice, would reload beets at a very reasonable rate. Piling grounds must be entirely level before the beets are laid down. Very little if any maintenance is necessary after the beets are reloaded. With road speeds of 16 m.p.h. the LD20 is able to load from several points within a 24-hour period. This tends to ease the railroad switching problem and to facilitate a more rapid recovery of "hot spots."

Crystallization of Sucrose with Sonic Waves[1]

ANDREW VANHOOK, W. F. RADLE, J. E. BUJAKE, AND J. J. CASAZZA[2]

The graining of sucrose syrups by sonic waves has already been reported in a preliminary way. (8) (9) (10) (11) (12)[4] This report continues these studies and considers the mechanism of the action in some detail.

Previous Work

There is a voluminous literature on the generation, properties, and effects of sonic and ultrasonic waves, (2) and some of it deals with crystallization processes. (4) Unfortunately, little of this latter small group is concerned specifically with sugar crystallization. A German patent (1) in which vibratory treatments are claimed to improve sugar boiling is one of the two publications which, to the writer's knowledge, has appeared since the last report from this laboratory. The other is a note (5) in which the author reports that he was unable to nucleate honey by prolonged irradiation. It is apparent from the data listed that considerable alteration of the syrups occurred during the treatment.

Method

A wide variety of sonic and ultrasonic equipment is available. The magneto-strictive type was used in most of the present investigations and the essential characeristics of this equipment are represented in Figure 1. The outstanding feature of this apparatus is the exceptional high power levels delivered by the transducers. These intensities, at their maxima, were estimated to be 4 and 14 sonic watts/cm.^{2} at 8 kc. and 1.1 mc., respectively.

Mechanism

It had been assumed in our earlier work (9) that a homogeneous mechanism is entailed in the formation of crystal nuclei by ultrasonic irradiation. However, careful observations on sugar solutions are not in accord with this hypothesis. The most convincing type of experiment indicating this situation is one in which the irradiation is performed under virtually sterile and isolated conditions. In this case, the otherwise usual positive effect is greatly reduced, and even absent in some cases. This suggestion of a heterogeneous mechanism is in accord with the

[1] This work was done under contract with the U. S. Department of Agriculture and authorized by the Research and Marketing Act of 1946. The contract was supervised by the Western Utilization Research Branch of Agricultural Research Service, Albany, California.

[2] Much of the work summarized in this paper is taken from the M.S. theses of Messrs. Bujake and Casazza.

[3] Department of Chemistry, College of the Holy Cross, Worcester, Mass.

[4] Numbers in parentheses refer to literature cited.

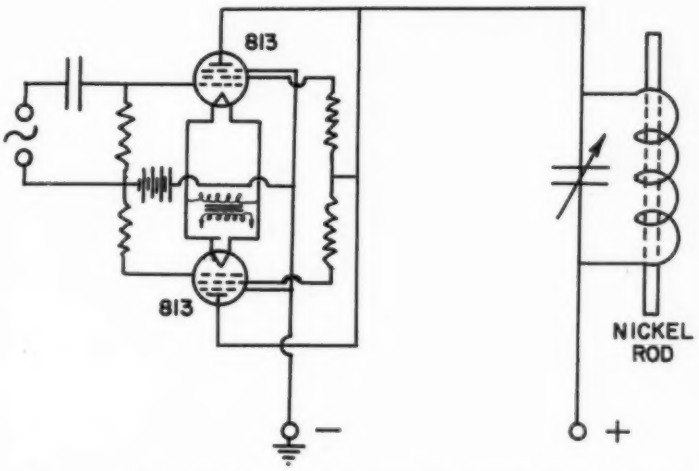

Figure 1.—The electronic circuit consisted essentially of a standard oscillator with sufficient grid driving power for one or two stages of power amplification. The above circuit, for example, is typical of the final stage used to drive magnetostrictive transducers.

For barium titanate transducers less power was usually required, a single stage being ample for the smaller transducers. These were inductively coupled to the final tank circuit.

calculation that the energy equivalent of even megacycle radiation is only calories per mole, whereas that required for homogeneous nucleation is of the order of kilocalories.

Under ordinary operating circumstances, truly homogeneous conditions do not prevail so that irradiation produces an apparent acceleration of the adjustment of supersaturated sugar solutions, just as in many other systems. This overall effect is the net result of simultaneous and consecutive nucleation and growth. Since nucleation without growth is impossible in a supersaturated environment, the separate contributions of these two steps must be resolved under conditions of growth without nucleation. This is accomplished by attaching a single crystal directly to the transducer bar. With this arrangement, it is observed that growth under irradiation proceeds only slightly faster than normal. Figure 2 displays the complete log of such a run. The slight increase (25 percent) under irradiation is more than reproduced (45 percent) by rotating the crystal at 200 r.p.m. without irradiation. Similar results are obtained at other concentrations and other frequencies; so that we may conclude that irradiation does not accelerate the absolute growth rate more than stirring at

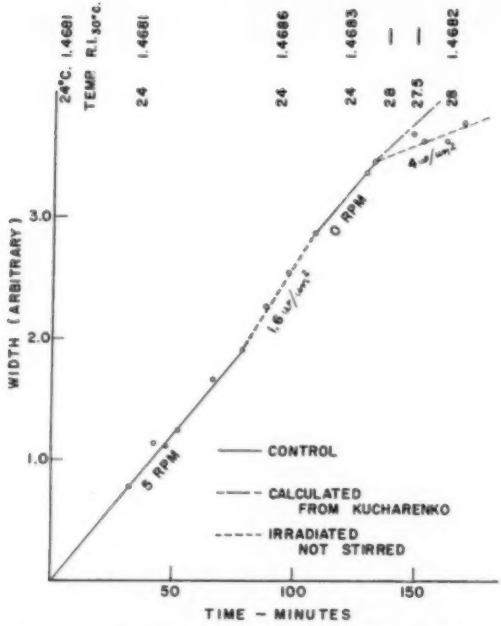

Figure 2.—Growth rate under irradiation at 8 kc.

200 r.p.m. The principal effect of irradiation is then on the nucleation process, and the following effects have been observed with solutions prepared in the usual manner.

Variables

Power. It is observed at effective frequencies that graining is produced only if exceedingly high power intensities are impressed. This more or less critical energy level is about 2 sonic watts/cm.^{2} at 8.8 kc., and corresponds with the onset of cavitation. Excess energy above this level is relatively ineffective. Figure 3 illustrates this pattern for several conditions. Similar results are realized at other frequencies and other temperatures, and the threshold power requirement remains between 1 and 2 sonic watts/cm.^{2} in all cases. Qualitative experiments indicate that the minimum power level is elevated by increased viscosity, but in the case of stronger solutions the enhanced effect of higher supersaturations is greater than the reduction occasioned by the increased viscosity.

Frequency. The 10^3 to 10^5 c.p.s. band of frequencies is found to be effective, provided the critical power level is exceeded.

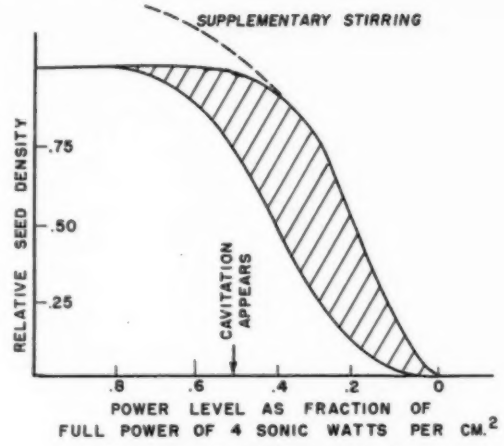

Figure 3.—Critical power level.

Within this spread there is a slight optimum at the 10^4 range. While most of the process variables reported here were observed at a frequency of 8.8 kc., they have been confirmed in a larger unit at essentially 28 kc. This latter frequency is above the audible range and is preferred for continued work.

Concentration. With all other conditions the same, the seed density developed by irradiation increases with respect to controls, as the supersaturation is increased. For instance, a typical series in which only the supersaturation was varied, follows:

Oversaturation	1.1	1.2	1.4	1.5	1.75	2.0	2.2
Relative seed density with respect to control	1.0	2.0	3.5	3.0	5.5	7.0	12

The reproducibility of such a series is not good since the footings generated depends upon the initial occurrence of foreign or potential nuclei. However, in similar experiments with seeded syrups, or with single crystal footings, the same increase in final seed density is observed as the concentration is increased.

Duration of Irradiation. Continued irradiation increases the crystal population in an autocatalytic manner. However, the uniformity of the final product suffers considerably as irradiation proceeds, since both nucleation and growth continue simultaneously during this period.

Nuclei Density. If one irradiates a strong syrup with the bar transducer, cavitation loci appear at definite points accord-

ing to the size, shape, and arrangement of the system. The crystal nuclei are generated, presumably within these small volumes. They may then be dispersed and grown to visible size in order to estimate the number created by the treatment. In this way, a density of approximately 10^8 per ml. of cavitation space was observed after irradiating a 20 percent oversaturated syrup at 30° C. for 10 minutes.

In another similar experiment in which the nuclei were dispersed as generated, a total of 1.5 x 10^6 centers was established throughout the entire space of 10 ml., or 1.5 x 10^7 per unit of originating volume. (These estimates of 10^7 to 10^8 nuclei/ml. may be compared to a typical graining procedure of about 10^5 particles/ml. of fondant in low grade work (3). The refractometric growth curve of this dispersion was then compared to those of known composition and found to be equivalent to a 1/30,000 slurry of 2 μ diameter seeds, 1/1,700 of 50 μ, or 1/330 of 160 μ particles. All four of these mixtures then contain approximately the same growing area of crystal footings. Since the area of a crystal is proportional to the square of its diameter, we may estimate that the size of the particles generated during the 10 minute irradiation is between 3 and 4 μ (4.0, 3.4, and 4.2 μ, respectively).[5] Since the linear growth during this period would have amounted to almost 20 μ, we may surmise that the sonic field has promoted a tremendous amount of false grain.

Temperature. No unusual effects of temperature are observed over the 30-70° C. range.

Natural Syrups. The above process variables were examined in detail with two beet syrups at standard thick juice and low machine grades, and no deviations from the white syrup patterns were observed. Similar tests on a low purity cane product yielded essentially the same results.

Uniformity. The stimulation of grain formation by sonic irradiation has led to the suggestion (10) that improved uniformity may result from such treatment. However, marked beneficiation in this respect results only after short periods of irradiation. During any extended exposure the dispersion of sizes continues to widen because of the simultaneous autocatalytic generation and growth processes. To minimize these divergent effects the treatment times must be extremely short, and to realize sufficient grain density the transducer area must be in-

[5] These calculations have been refined to account for the distribution of sizes and accretion during the exposure time. The analysis does not reduce the above estimate by more than an order of magnitude. It is suggestive to point out that this size (10^4 to 10^5 cm.) is within the domain of the mosaic theory of the structure of solids, but well above that (10^6 to 10^7 cm.) of the critical nucleus required for homogeneous nucleation.)

creased to multiply the seed density to the population required for the finished strike.

None the less, even with this limitation it has been possible, in experimental strikes with the bar transducer, to realize uniformities of 20 percent or less, as expressed by the coefficient of variation (2). It appears likely that this figure may be improved in a new pilot plant unit which has been constructed recently.

Summary and Conclusions

The mechanism of sound activity is heterogeneous, and not homogeneous.

Treatment with sonic waves accelerates the adjustment of supersaturated sucrose solutions, both pure and impure. This treatment has no special effect on the rate of growth of single sugar crystals, so that the observed overall increase is due almost entirely to enhanced nucleation by false grain formation.

The effects of sonic graining become more pronounced with increasing supersaturation and time of irradiation. A threshold power level of about 2 sonic watts/cm.^{2} is necessary to obtain any significant results, and excess energy above this level is relatively ineffective. The optimum frequency is in the neighborhood of 10 Kcs. No unusual effects have been observed over the temperature range 30-70° C.

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Preliminary Studies on Reciprocal Recurrent Selection in Sugar Beets[1]

LeRoy Powers, R. E. Finkner, C. W. Doxtator, and J. F. Swink[2]

Comstock, Robinson, and Harvey (1)[3] proposed reciprocal recurrent selection as a breeding procedure designed to make maximum use of both specific and general combining ability. Preliminary studies on reciprocal recurrent selections with sugar beets provide information pertaining to the solution of problems arising from the application of this method of breeding.

Some of these problems are as follows: 1. determining the proportion of progeny resulting from fertilization by the opposite source; 2. designing planting arrangements that give the desired amount of fertilization between plants of different sources and between plants within a given source; 3. obtaining precision in selection; 4. obtaining sufficient amounts of seed from each mother beet to provide adequate yield tests of the respective progeny; and 5. perpetuation of the genotypic complex of the mother beet whose progeny are being tested.

Certain formulas and procedures not previously available aid in the solution of these problems. The purpose of this article is to present such formulas and procedures together with other information pertaining to their solution.

Materials and Methods

The plant material consisted of 600 roots selected from the variety American Crystal 3S. Those beets having green hypocotyls were designated as source A and those having red hypocotyls as source B. These 600 roots were quartered to provide for planting three different isolation plots.

Two isolation plots, one of the A source and one of the B source, were planted near Salida, Colorado, two quarters from each beet of the respective source being planted in each isolation plot. The purpose of these plots was to obtain seed resulting from self fertilization. As many of the flowering branches as time and facilities would permit were bagged to control pollination.

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[2] Geneticist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Manager Research Station, Plant Breeder, and Station Superintendent, American Crystal Sugar Company, Rocky Ford, Colorado, respectively.

[3] Numbers in parentheses refer to literature cited.

Diagram 1.—Sectional Portion of the Planting Arrangement for Sources A and B Showing the Position in the Isolation Plot of the Two Quarters of Each Beet, Grown in 1955 at Fort Collins, Colorado.

A1	B2	A3	B4	A5	.	.	.	B30
A1	B2	A3	B4	A5	.	.	.	B30
B60	A59	B58	A57	B56	.	.	.	A31
B60	A59	B58	A57	B56	.	.	.	A31
A61	B62	A63	B64	A65	.	.	.	B90
A61	B62	A63	B64	A65	.	.	.	B90
B120	A119	B118	A117	B116	.	.	.	A91
B120	A119	B118	A117	B116	.	.	.	A91
A121	B122	A123	B124	A125	.	.	.	B150
A121	B122	A123	B124	A125	.	.	.	B150
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
B600	A599	B598	A597	B596	.	.	.	A571

The two remaining quarters of each beet were planted on the Agronomy Farm of Colorado State University at Fort Collins, Colorado. The planting arrangement of the two sources are shown in Diagram 1. Actually only 170 of the 600 selected beets had green hypocotyls. In planting, the two quarters of each of these 170 beets were alternated with two quarters from source B as shown in Diagram 1. They were planted in the middle of the isolation plot. The spacing was 3 feet between rows and 3 feet between beets within a row.

Of the 170 mother beet selections having green hypocotyls 166 produced sufficient seed to warrant their being included in the study. Only 136 of the green hypocotyl selections were surrounded by source B and other source A plants as indicated by the solid line in Diagram 1. Only the progeny of these 136 mother beets were employed in calculating the proportion of the offspring resulting from fertilization by source B gametes. However, the entire 166 selections of source A and 170 selections of source B should be (according to Diagram 1) and were used in the calculation of the relative proportions of the two-genotypic gametes fertilizing the ovules of the source A plants.

Of the 600 plants in the isolation plot at Fort Collins, 490 produced sufficient open-pollinated seed and seed from self pollination to warrant including open-pollinated seed in progeny yield of roots and percentage sucrose tests. The design of the experiment was a modified randomized complete block with five blocks (replications). The 490 progenies were divided into

49 groups of 10 progenies each. The groups for each of the five replications were determined at random. That is, the 490 progenies were randomized within replications and then the two checks were randomized within each of the 49 groups of 10 progenies. This procedure was followed for each of the five replications. The checks were American Crystal 3S and US 401. Hence, there were 49 cultures of American Crystal 3S and 49 cultures of US 401 per replication. In this study the 49 groups within each replication composed of 12 populations each are designated as series. The plot consisted of one row 20 feet long and the beets within the row were thinned to a 10-inch spacing. Four replications were grown at Mason City, Iowa, and one was grown at Waseca, Minnesota. Excellent stands were obtained in all five replications.

The checks were used to estimate the environmental variance. The F value of an analysis of variance of the two checks for all replications revealed that the probability of the variance of the first order interaction of populations X series being significantly different from the variance of populations X replications X series was exceedingly small for both weight of roots per plot and percentage sucrose. Hence, the variance of populations X replications X series was used as an estimate of the environmental variance and applied as described below to detect superior performing progenies.

Fisher's (2) Table 1 was used to obtain the value of P. The value of x (see Fisher, 2, Table 1) is $(X\text{-}\overline{C}) \div [Vprs + (Vprs/2)]$. The symbol designations are as follows:

X = the value for any given progeny within a series

$\overline{C}$ = the average of the two checks in the same series as the progeny being evaluated

Vprs = the variance of populations X replications X series

In selection experiments based on progeny performance, as are these, the P values for only the most promising progenies need be calculated. The final selection is based on the performance of such progenies in all five replications.

Results

Formula for and Determination of Percentage of Fertilization of Source A Female Gametes (rr) by Source B Male Gametes (RR and Rr)

In determining the percentage of fertilization of source A female gametes by source B male gametes the formulas for predicting gene frequency as given by Li (5) are employed. These formulas are based on those used by Hardy and Weinberg in

developing the Hardy-Weinberg law (see Hardy, 4 and Weinberg, 8). They are: $p = \frac{D + \frac{1}{2}H}{N}$ and $q = \frac{\frac{1}{2}H + R}{N}$.

The letter designations have the following connotations in this article:

p = the proportion of male gametes carrying R genes
q = the proportion of male gametes carrying r genes
D = the number of plants of the RR genotype in the mother beet population
H = the number of plants of the Rr genotype in the mother beet population
R = the number of plants of the rr genotype in the mother beet population
N = the total number of individuals in the mother beet population

The values for these designations are:

D = 73 H = 97 R = 166 N = 336

Substituting these values in the formula we have

$p = \frac{73 + 48.5}{336} = 0.3616$, and $q = \frac{48.5 + 166}{336} = 0.6384$.

The progeny of 136 of the rr mother beets were classified for hypocotyl color. There were 24,121 plants in these 136 progenies, 11,796 of which had red hypocotyl color and 12,325 of which had green hypocotyls. The proportions are red hypocotyl color 0.4890 and green 0.5110. The theoretical expected on the basis that the population is panmictic and that there is random union of gametes is 0.3616 red hypocotyl plants and 0.6384 green hypocotyl plants. Since these progenies are from the rr plants, the male gametic output as regards the genes conditioning hypocotyl color is measured directly. Hence, of the 24,121 plants of these 136 progenies from rr plants, 8,722 would be expected to have red hypocotyls and 15,399 would be expected to have green hypocotyls. Comparing these with the obtained given above, without further statistical analysis, it is apparent that there is a greater proportion of the A source plants being fertilized by R gametes which come only from the B source than expected on the basis of panmixia and random union of gametes. The percentage of the progeny resulting from fertilization by the B source is important, because the percentage of fertilization of source A ovules with the gametes from source B provides a measure for determining the extent to which tests conducted with resulting progeny measure the combining ability of source A fertilized by source B.

The estimation of the percentage of the progeny resulting from ovules of source A fertilized with gametes from source B requires formulas which are readily developed from those given by Li (5). Let p′ equal the proportion of the source A ovules (rr plants) fertilized by male gametes carrying the R gene. Then p′ equals $\frac{D' + H'}{N'}$ in which D′ + H′ is the number of plants among the progeny of source A plants having red hypocotyls and N′ is the total number of plants in this progeny. Let x equal the proportion of the progeny of A source plants resulting from fertilization by B source. Then the formula for determining the proportion of the progeny of source A resulting from fertilization by source B gametes is $x = \frac{(D + H)\,p'}{D + \frac{1}{2}H}$. One of the functions of this formula is to take into consideration r gametes from source B plants.

By substituting in the formula, $x = \frac{(73 + 97)\,0.4890}{73 + 48.5} = 0.6842$. Hence the percent of the progeny of source A resulting from fertilization by source B gametes is 68.42. Hence 68.42 percent of the progeny of source A plants had source B as the male parent and 31.58 percent (100.00 − 68.42) resulted from fertilization between plants within the A source. This 31.58 percent of the progeny includes those resulting from self fertilization.

Since 68.42 percent of the progeny had source B as the pollen parent, it seems that probably there was comparatively little self fertilization of plants within the A strain and hence most of the 31.58 percent of the progeny resulting from fertilization within the A strain would be expected to have resulted from fertilization between plants within the source.

Formulas for Determining the Percentage of Fertilization by Source A Male Gametes of Source B Female Gametes Produced by Rr Mother Beets

Since, in this study, the only difference between sources A and B was hypocotyl color the findings for source A as to the percentage of the progeny having source B plants as the male parent should apply equally well to the percentage of the progeny of source B plants having source A plants as the male parent. It does not seem appropriate to pursue the inquiry as to the actual amount of cross fertilization between plants of different sources further because the material under study is of extremely limited interest. However, the formulas for determining the percentage of fertilization by source A male gametes of those source B female gametes produced by Rr mother beets

have wide application in breeding sugar beets and other crops. Hence, the formulas are given and their applications are illustrated.

As before, gene frequencies for the male plants are calculated from the formulas given by Li (5). Again D = 73, H = 97, and R = 166. Only the progeny of the source B plants having the genotype Rr will be considered because all the progeny of the RR genotypic plants would have red hypocotyls. Let D′ equal the proportion of the progeny of Rr plants having the genotype RR, H′ equal the proportion of the progeny of Rr plants having the genotype Rr, and R′ equal the proportion of the progeny of Rr plants having the rr genotype. It follows from Li's (5) formula that $D' = \frac{1}{2}p$, $H' = \frac{1}{2}(p + q)$ and $R' = \frac{1}{2}q$. Hence the theoretical proportion of the progeny of Rr plants having red hypocotyls is $p + \frac{1}{2}q$ and the theoretical proportion having green hypocotyls is $\frac{1}{2}q$.

With the above formulas in mind formulas are readily developed for determining the proportion of progeny of Rr source B plants resulting from fertilization of source A gametes. Let $\frac{1}{2}q'$ be the proportion of green hypocotyl plants among the progeny of Rr source B plants. Then using the same symbol designations as before $p' = 1 - q'$, and the formula for determining the proportion of the progeny of source B (Rr plants) that result from fertilization by source A gametes is

$$x = 1 - \frac{(D + H)\,p'}{D + \frac{1}{2}H}$$

Accepting the results based on the studies with the A source plants (rr genotype) $\frac{1}{2}q' = 0.387150$. By substituting the values in the formula, $p' = 1 - 2(0.387150) = 0.2257$ and $x = 1 - \frac{(73 + 97)\,0.2257}{73 + 48.5} = 1 - 0.3158 = 0.6842$. It must be kept in mind that the value of 0.6842 is obtained by accepting the results of the study of the progeny of source A plants and the value of 0.387150 based on 0.6842 is used solely to illustrate the application of the formula for determining the proportion of the progeny of source B plants resulting from fertilization by source A gametes.

Proposed Planting Arrangement Designed to Result in a Higher Proportion of the Progeny Having Been Fertilized by Male Gametes from the Opposite Source

In some breeding programs it may be desirable to have a higher proportion of the progeny result from fertilization by

Diagram 2.—Sectional Portion of a Planting Arrangement Providing that a Higher Proportion of the Progeny from Source B Result from Fertilization by Gametes from Source A.

A1	A3	B2	A5	A7	B4
B8	A15	A13	B6	A11	A9
A17	A19	B10	A29	A23	B12
B16	A1	A3	B14	A5	A7
A15	A13	B18	A11	A9	B20
B24	A17	A19	B22	A21	A23

male gametes of the opposite source. Diagram 2 presents a sectional portion of a planting arrangement providing that a higher proportion of the progeny from source B results from fertilization by gametes from source A. In this planting arrangement there are two source A plants to one source B plant. In the planting arrangement depicted in Diagram 1 the ratio is one source A plant to one source B plant. This latter planting arrangement resulted in 68.42 percent of the progeny having arisen from fertilization by the opposite source.

In the planting arrangement shown in Diagram 2 two quarters of A are used to one quarter of B. Thus, considerably more than 68.42 percent of the progeny grown from noncontrolled-pollinated seed of source B plants would be expected to have source A plants as the male parent. That such is probable can be seen by examining the areas in Diagram 2 blocked out by the solid line. Conversely, the noncontrolled-pollinated seed from source A plants would be expected to have a higher proportion of the progeny resulting from fertilization between plants within source A. To complete the plantings for the reciprocal recurrent selection method another isolation plot is required in which two quarters of A are planted and one quarter of B for each mother beet. Thus three of the four quarters of each beet would be used in the two seed plots to obtain cross-fertilized seed for progeny tests. The mother beet genotypes would be maintained by planting the fourth quarter under controlled temperature and light in an endeavor to cause reversion to the vegetative condition, or in the event the physiological conditions necessary to seed production had not been induced, to maintain it in the vegetative condition.

Preserving the Genotypic Complex of the Mother Beets Whose Progeny Are Being Tested

In a planting arrangement such as shown in Diagram 2 self-pollinated seed of the A source is obtained and in the second isolation plot in which source B plants predominate self-pollinated seed is obtained from source B plants. Bagging is employed to obtain this self-pollinated seed. If sufficient self-pollinated seed were obtained, this would be an effective means of preserving the genotype of the mother beets. However, such is not always the case, and therefore another method of preserving the genotype of the mother beets is needed.

Owen and others (6) tested vernalization techniques with sugar beet seed and found it a practical measure for hastening reproduction under greenhouse conditions. Gaskill (3) demonstrated that a combination of continuous light and low temperature exposure to seedlings can be used to bring about two generations a year of biennial sugar beets.

Hence, these experiments on inducing reproduction indicate that it might be possible to preserve the genotype of each mother beet by causing reversion of one or more quarters to the vegetative condition or by maintaining them in the vegetative condition.

Figure 1 illustrates the results from studies to asexually preserve the genotype of 32 mother beets selected from approximately 10,000 plants of G. W. 359-52R. Figure 1A shows the seed stocks grown from ½ of each beet. These plants were kept under continuous light until the flower buds were well established and the night temperatures ranged from 45 to 55 degrees F., the day temperatures from 65 to 75 degrees F. Figure 1B shows two quarters of each mother beet under a light period occurring during the day and under temperatures ranging from 60 to 65 degrees F. during the night, and ranging from 75 to 85 degrees F. during the day. These beets had been placed in the root cellar on October 5 and transplanted into the greenhouse on November 27, 1956.

As Figure 1A shows, the plants under continuous light and comparatively low temperatures produced seed, whereas those under the short light period and comparatively higher temperatures remained vegetative or reverted, whichever the case may be. Figure 1B shows that the plants given a period of light normal during the days from November 27 remained in the vegetative condition. These together with the self-pollinated seed should be sufficient to preserve the genotype of those mother beets whose progeny may prove to be superior, and hence desired for further genetic and breeding studies.

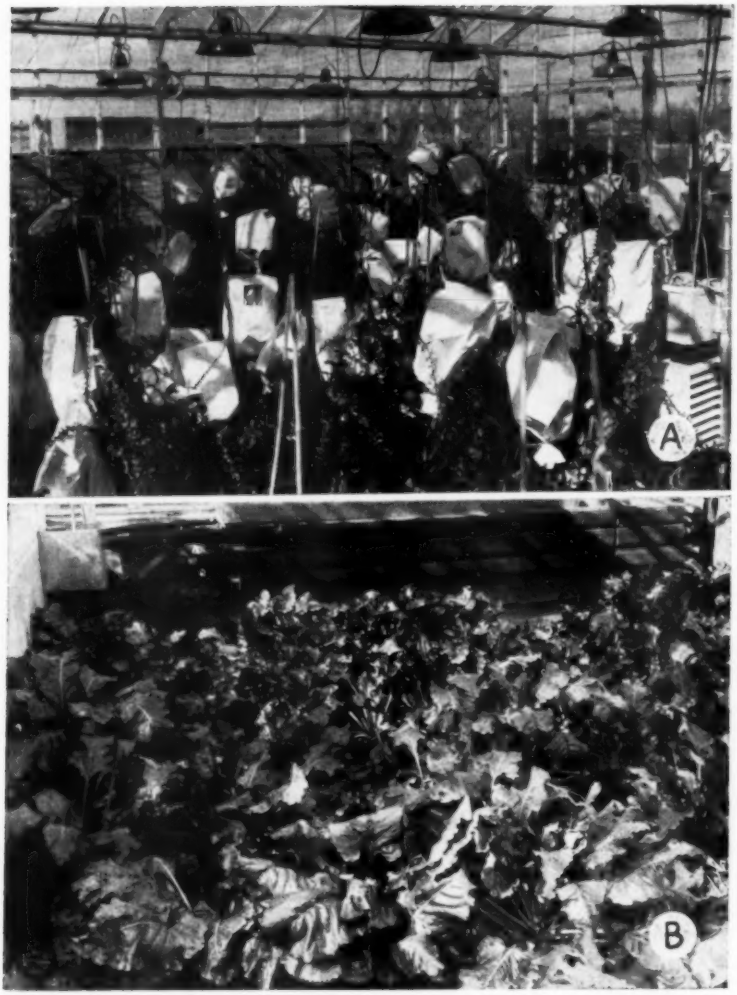

Figure 1.—(A) Seed and seed stocks produced on plants grown from one-half of each mother beet. (B) Plants in the vegetative condition grown from two quarters of each mother beet.

Probabilities of Certain Progenies from Mother Beets Selected from American Crystal 3S Being Superior to the Checks

The probabilities of certain progenies of mother beets selected from American Crystal 3S being superior to the average of the two checks are given in Table 1. The characters considered are weight per plot and percentage sucrose. The data shown are for only eight of the progeny of the 490 mother beets. It will be remembered that the two checks were American Crystal 3S and US 401. The F values obtained from an application of analysis of variance showed that the two checks did not differ significantly in weight of beets per plot but that American Crystal averaged 0.4 percent more sucrose than US 401. The odds against this value of 0.4 percent being a chance deviation were extremely great.

Table 1.—The Probability of Certain Progeny (Indicated by 1955 Culture Number) Falling Outside —x to +x (See Fisher, 2, Table 1) for Weight Per Root and Percentage Sucrose, the Probability (P) Being Based on the Difference Between Any Given Progeny and the Average of the Two Checks.

1955 Culture Number	Weight Per Plot					Percentage Sucrose				
	Replication					Replication				
	1	2	3	4	5	1	2	3	4	5
	P	P	P	P	P	P	P	P	P	P
6148	0.36	0.06	0.27	0.75	0.12	0.21	0.72	0.19	.....	.....
6221	0.08	0.48	0.60	0.11	0.44	0.52	.....	.....	0.05	.....
6440	0.02	0.09	0.15	0.43	.....	0.81	0.05	0.67	0.44	0.01
6444	0.08	0.67	0.46	0.06	0.70	0.34	.....	0.95	0.56	.....
6506	0.06	0.49	0.03	0.14	0.83	.....	0.86	.....	0.34	0.63
6551	.....	0.90	0.33	0.20	.....	0.00	0.32	0.60	0.11	0.72
6585	0.03	.....	.....	0.42	0.96	0.04	0.48	0.81	0.21	0.02
6590	0.14	0.45	.....	0.71	0.74	0.14	0.72	0.34	0.28	0.95

..... Values less than the average of the two checks.

A study of Table 1 reveals that none of the progenies exceeded the checks in all the replications for both weight per plot and percentage sucrose. Four of the eight progeny exceeded the check in weight per plot in all five replications and four exceeded the average of the checks for percentage sucrose in all five replications. The selfed seed from 25 of the mother beets whose progeny showed the most promise are being grown for the purpose of producing a synthetic variety. It remains to be determined whether such a synthetic variety will be superior to

American Crystal 3S in yield of beets per acre, percentage sucrose, or both characters. This procedure of producing a synthetic variety from the self-pollinated plants of the 25 mother beets whose progeny showed the most promise is essentially the polycross method of breeding.

If the plant breeder desired to follow the reciprocal recurrent selection method of breeding with this material the procedure would be as follows: Seed produced from self-pollination of mother beets of source A having the most promise, as shown by the progeny test, would be planted to produce mother beets that in turn would be intercrossed to give source A for the second cycle of breeding. Likewise seed produced from self-pollinated mother beets of source B having the most promise, as shown by the progeny test, would be planted to produce mother beets for intercrossing to give source B for the second cycle of breeding. Since it was found that crossing between sources that yielded the seed planted in the progeny test was 68.42 percent, differentiation of the two sources would have started. In other words, due to the greater preponderance of the progeny having resulted from fertilization by gametes of the opposite source the accumulation of genes in each source that combined well with genes of the opposite source would be under way.

Discussion and Conclusions

Two planting arrangements given differ in the amount of crossing that would be expected between sources. It was found from the planting arrangement given in Diagram 1 that 68.42 percent of the progeny of source A had source B plants as the male parent. Since the only difference between sources was hypocotyl color this same percentage of the progeny from the source B mother beets would be expected to have had source A plants as the pollen parent. Hence only 31.58 percent of the progeny of the two sources would be expected to have resulted from self fertilization and fertilization between plants within sources. The comparatively high percentage of crossing between sources indicates that very little self fertilization is occurring in this material. Hence, most of the 31.58 percent resulting from either self fertilization or fertilization between gametes within sources would be expected to have resulted from the latter type of fertilization.

Diagram 2 presents a suggested planting arrangement that should result in a higher proportion than 68.42 percent of the progeny resulting from fertilization between gametes of the opposite sources. The question arises whether more than 68.42

percent of the progeny resulting from fertilization between gametes of different sources is necessary or desirable. The 31.58 percent of progeny resulting from fertilization by gametes of different plants within sources would tend to keep the two sources in a more heterozygous condition and hence to avoid a too rapid approach towards homozygosity. This is important as improvement in the further cycles of reciprocal recurrent selection is dependent upon heterozygosity and heterogeneity within sources.

In the planting arrangements depicted by Diagrams 1 and 2, if facilities are ample and the breeder so desires, the following methods of breeding designed to take advantage of any beneficial heterosis may be practiced from each planting arrangement. From the isolation plot of source A and the isolation plot of source B (in this study grown near Salida, Colorado,) open pollinated seed saved from each plant would provide for polycross tests (or recurrent selection tests) and hence allow employing this method of breeding. Seed saved from the open pollinated plants in the isolation plot depicted in Diagram 1 (in this study grown at Fort Collins, Colorado,) would allow practicing the reciprocal recurrent selection method of breeding. As pointed out by Comstock, Robinson, and Harvey (1) inbreeding within sources to establish inbred lines could be started at any time. However, it seems that the number of inbred lines that it would be necessary to produce and test for combining ability could be materially reduced by doing the inbreeding within sources after at least two or three cycles of reciprocal recurrent selection had been completed.

Following the planting arrangement depicted in Diagram 2, seed resulting from open pollination and saved from A source plants would allow practicing the polycross method of breeding; and seed saved from the B plants would allow following the reciprocal recurrent selection method of breeding. In the corresponding isolation plot in which B plants predominated, the polycross method of breeding could be followed by saving seed resulting from open pollinated B plants; and the reciprocal recurrent selection method could be practiced by saving seed resulting from open pollinated A plants.

The findings from the studies with 600 mother beets as regards the amount of cross fertilization are of further interest in connection with the extent to which the progeny tests measure general and specific combining ability. On the average 68.42 percent of the progeny from any given mother beet resulted from fertilization between plants of different sources, and 31.58 percent from fertilization between plants within sources and from

self fertilization. The data indicated that the amount of self fertilization was negligible. Hence, in this material, on the average the performance of 68.42 percent of the progeny from any given mother beet measures general and specific combining ability between sources and the performance of 31.58 percent of the progeny from any given mother beet predominantly measures general combining ability within the respective source. However, as the program employing reciprocal recurrent selection progresses the 68.42 percent of the progeny resulting from fertilization between plants of different sources tends more and more to emphasize specific combining ability. For definition and usage of the terms, general and specific combining ability, see Sprague and Tatum (7) and Comstock, Robinson, and Harvey (1).

It seems probable from the studies reported herein, that the genotypes of each mother beet in the tests for combining ability could be retained by a combination of self pollination and maintaining in the vegetative condition, or bringing about reversion to the vegetative condition one quarter of each mother beet. In following such a procedure in the planting arrangement depicted in Diagram 1, bagging of flowering branches should be practiced in all isolation plantings; that is, in the planting in which plants of sources A and B are grown together and in the plantings in which sources A and B are grown separately. In the planting arrangement depicted in Diagram 2 flowering branches of the A plants should be bagged in an attempt to bring about self fertilization, and source B plants should be similarly treated in the corresponding isolation plot in which B plants predominate. In this latter planting arrangement it seems that all the seed from those plants of the source in the minority should be saved for progeny tests. Hence, bagging to bring about self fertilization and propagation of a quarter of each beet in the vegetative condition should make it possible to retain the genotype of each mother beet whose progeny are being tested.

Another point of interest is the effect that reciprocal recurrent selection would have on progressive changes in the amount of cross fertilization as compared with self fertilization. It can be seen that, if heterosis is playing an important part in conditioning favorable economic characters, as the program progresses those individuals having any appreciable amount of self fertilization would be less desirable and hence would be eliminated. Then, as the breeding program progressed a greater proportion of the progeny would result from cross fertilization and finally

a very high proportion of the progeny would result from this type of fertilization. The reciprocal recurrent selection program would be particularly effective in bringing about a higher percentage of cross ferilization when either sources A or B, or both, at the beginning of the breeding program were low in this respect.

One of the most important aspects of the reciprocal recurrent selection program is precision of tesing the progeny for the characters sought. In order to make the selections within a small area and thus lower the environmental effect on selection each replication of 588 populations was divided into 49 series with two checks in each series. The 49 checks of each variety per each of five replications provided a measure of the environmental variance. Any given progeny was evaluated on the basis of the average of the two checks in the series in which it occurred. Since any given progeny occurs in each replication, five such determinations (see Table 1) are available for evaluating any one of the 490 progeny. Growing the five replications at a single location might result in a hybrid that would have limited adaptation. However, if the five replications were distributed over the area in which the hybrid is to be grown the probability of such happening would be reduced materially. In the present experiment the progeny were grown at two locations, Mason City, Iowa, and Waseca, Minnesota. Further studies are necessary to determine the effectiveness of this method of evaluating the progeny.

Summary

1. The formulas developed for determining the proportion of the progeny resulting from fertilization by male gametes of the opposite source are:

(A) Progeny from source A mothers (rr genotypic plants)

$$x = \frac{(D + H)\,p'}{D + \frac{1}{2}H}$$

(B) Progeny from source B mothers (Rr genotypic plants)

$$x = 1 - \frac{(D + H)\,p'}{D + \frac{1}{2}H}$$

The applications of these formulas are illustrated.

2. Two different planting arrangements are proposed that should provide different amounts of cross fertilization between plants of opposite sources. Others not presented that are obvious may prove superior.

3. Self pollination and maintaining in or causing reversion of quarters of each mother beet to the vegetative condition were found effective in preserving the genotype of each mother beet whose progeny was under test.

4. The method employed in testing the progeny of the 490 mother beets proved satisfactory in the present study. However further studies are needed to determine precision of selection based on this method of testing the progeny.

5. The planting arrangement described in Diagram 1 provided sufficient seed to test the progeny of 490 of the 600 mother beets with which the research was started.

6. Under *"Discussion and Conclusions"* applications of the findings to a plant breeding program are presented.

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Theoretical Steady State Distribution of an Additive in Sugar Beet Diffusers

FRED STITT[1]

Introduction of an appropriate chemical into a diffuser may be considered for any of several purposes such as the suppression of microbiological action or the control of texture of the pulp. The additive may be introduced at various points in the diffuser either intermittently or in an essentially continuous manner. This paper considers the question of how the additive becomes distributed in the various portions of the diffuser and between the juice and pulp leaving the diffuser. Provided certain assumptions hold, this distribution can be simply expressed for the steady state reached in the case of a diffusion battery consisting of discrete cells to one of which a fixed amount of additive is introduced after each transfer step. Following presentation and discussion of the results for the steady state distribution of additive in such a model battery, the modifications required for similar batteries operating in accord with less restrictive assumptions and for continuous diffusers are discussed. The time required to reach a steady state is also briefly discussed. All mathematical derivations are contained in the appendix.

Model Battery

Let the cells of the battery be numbered serially. The cossettes enter the first cell and leave the last cell as pulp, while the battery supply water enters the last cell and leaves the first cell as juice. In this paper a model battery is defined as one for which the following assumptions hold:

1. Each cell contains the same volume of cossettes, V_c, and the same volume of juice, V_J. At each transfer the contents of each cell are completely replaced, the volume V_c of cossettes of any particular cell moving to the next higher numbered cell and the volume V_J of juice moving to the next lower numbered cell.

2. The additive present in each cell immediately after a transfer becomes distributed so that immediately prior to the next transfer the ratio of the amount of additive associated with the juice to the amount of additive associated with the cossettes is the same in each cell, viz. the partition ratio d.

3. No additive is consumed or produced by reactions taking place in any cell.

When steady state conditions are attained in an n-celled model battery to the m^{th} cell of which the amount of additive a is intro-

[1] Agricultural Research Service, U. S. Department of Agriculture, Western Utilization Research and Development Division, Albany 10, California.

duced after each transfer, the amount of the additive which leaves the battery with the pulp at each transfer is

$$P = \left(\frac{d^m-1}{d^{n+1}-1}\right) a$$

and the amount which leaves the battery with the juice is

$$J = a-P = \left(\frac{d^{n+1}-d^m}{d^{n+1}-1}\right) a$$

Under steady state conditions the amount of additive in the i^{th} cell is $A_i = \left(\frac{d+1}{d-1}\right) J \ (1-d^{-i})$ for $i = 1$ to m,

and $A_i = \left(\frac{d+1}{d-1}\right) P \ (d^{n+1-i}-1)$ for $i = m$ to n.

The total amount of additive in the battery is then

$$T = \left(\frac{d+1}{d-1}\right) [ma-(n+1) \ P]$$

Evaluation of these expressions for d equal to unity gives

$$P = \frac{ma}{n+1},$$

$$A_i = 2iJ \qquad \text{for } i = 1 \text{ to } m,$$

$$A_i = 2(n+1-i) \ P \qquad \text{for } i = m \text{ to } n,$$

and $$T = (n+1-m) \ ma.$$

Derivation of these results is given in the appendix.

Examination of these mathematical expressions leads to several generalizations applying to steady state conditions in a model battery to which the same amount of additive is introduced in a particular cell following each transfer:

1. Regardless of its position, the cell into which the additive is introduced (the add cell) contains more additive than any other cell.

2. For any specified value of the partition ratio d, the amount of additive in the add cell is the same when it is the $(n\text{-}m)^{th}$ cell as when it is the m^{th} cell, regardless of the value of m.

3. For any specified value of d, the add cell contains more additive the closer it is located to the center of the battery.

4. Regardless of its position, the add cell contains more additive the closer d is to unity.

5. For a battery operated so that d is unity, the additive is distributed linearly between the add cell and each end cell.

6. The further d is from unity, the more non-linear is the distribution of additive between the add cell and each end cell. When the partition ratio is greater than unity this non-linearity is in the direction of more additive than linear distribution for cells ahead of the add cell (i less than m), and less for cells behind the add cell. This non-linearity is in the opposite direction for d less than unity.

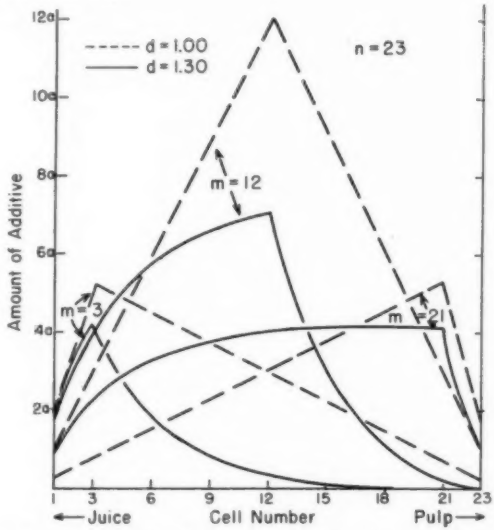

Figure 1.—Steady state distribution of additive in a 23-cell model battery for two values of the partition ratio d and three positions (m) of the add cell. Quantities shown are the steady state amounts of additive in each cell where a is the amount introduced in the add cell after each transfer.

These generalizations are illustrated in Figure 1 where the calculated steady state distributions are shown for a 23-cell battery for two values of d and for three different positions of the add cell. Although drawn as smooth curves or straight lines in the figure, these results have significance only for the points corresponding to integral cell numbers, the ordinate being the amount of additive present at the steady state in the cell number shown as abscissa. For example, when the add cell is at the center of the battery ($m = 12$), it contains $12a$ units of additive at the steady state for a partition coefficient of unity ($d = 1.00$). It is at once apparent from the figure that the amount of additive in a cell may be many times or a small fraction of the amount

added after each transfer depending on the value of d and the position of the cell with respect to the add cell.

If it is desired to maintain in all cells a concentration of additive greater than some specified minimum value, the correct choice of add cell is that for which the steady state amounts of additive in the first and last cells of the battery are most nearly the same. This location moves from the center of the battery for $d = 1$ progressively nearer the pulp end as d is increased above unity. For the case $n = 23$, $d = 1.30$, the correct choice of feed cell for this purpose is $m = 21$. In general its location is given by the integral value of m nearest that for which $d^{m-1} = \frac{d^n+1}{d+1}$, and $\frac{a}{P(1+d)}$ or $\frac{da}{J(1+d)}$, whichever is larger, is the amount of additive which must be introduced after each transfer to maintain at least a units of additive in each cell.

The proportion of additive leaving a model battery in the

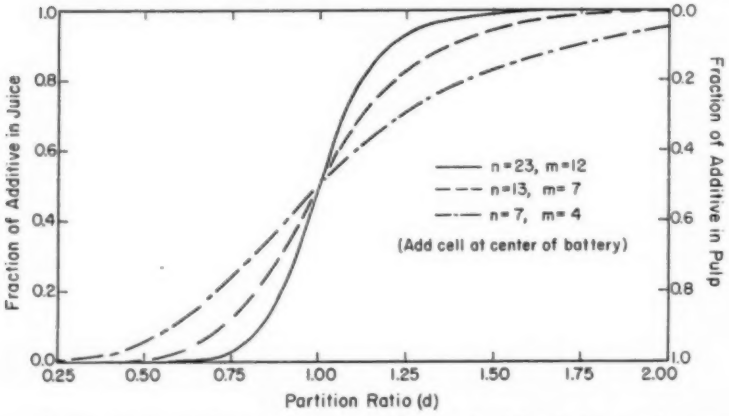

Figure 2.—Dependence on the partition ratio *(d)* of the steady state fractions of additive appearing in the juice and pulp when the add cell is at the center of model batteries containing 7, 13, and 23 cells.

juice depends on the number of cells in the battery, the value of the partition ratio, and the location of the add cell. The dependence on n and d is shown for steady state conditions in Figure 2 for introduction of the additive at the center of the battery. Either an increase in the number of cells or a shift of d value away from unity leads to a preponderance of additive being discharged from the juice end of the battery for d greater than unity and from the pulp end for d less than one. The effect of the position of the add cell on the emergence of the additive

from the battery is shown for selected values of d for a 23-cell model battery at steady state conditions in Figure 3. Thus for $d = 1.30$, the proportion of additive leaving the 23-celled battery in the juice may be varied from 23 to 99.94% by varying the location of the feed cell.

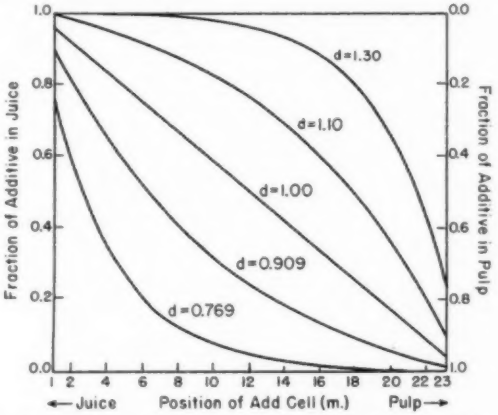

Figure 3.—Dependence on the position of the add cell of the steady state fractions of additive appearing in the juice and pulp of a 23-cell model battery for five different values of the partition ratio *(d)*.

Some Non-Model Batteries

The expressions given above are also useful in describing batteries which deviate in certain ways from satisfying assumptions 1 and 2 for a model battery. First, there may not be a clean separation of the juice from the cossettes when a transfer is made. Provided the same fraction of the juice phase is transported with the cossettes from each cell at transfer and the assumptions made for the model battery are otherwise valid, the above equations are still applicable, the only change being that the partition ratio then has a different value than if a clean separation were made. This is demonstrated in the appendix.

Another situation described by the model battery equations is that where some of the contents of each cell are allowed to remain in the cell at each transfer. Provided the relative amounts of additive associated with the portions transferred in each direction and with the portion remaining are the same for each cell at transfer, and provided the model battery assumptions are otherwise valid, the expressions given for P and J are still applicable. The expressions for the amount of additive in each cell and the total amount of additive in the battery are each increased by the factor $(1+a)$ where a is the ratio of the amount

of additive remaining in the cell to that which is removed from the cell at each transfer. These statements are also verified in the appendix.

A third case for which the results for a model battery can be modified to apply is that for which the additive in each cell does not reach equilibrium distribution between the juice and cossette phase prior to each transfer, but where equilibrium is approached in a particular manner in each cell as discussed below. Except when the additive is introduced via the battery supply water or the fresh cossettes, the assumption for a model battery that the partition ratio is the same for all cells implies that equilibrium distribution of additive is reached in each cell prior to each transfer. This can be readily seen by considering the movement of a portion of additive after its introduction into cell m. If the additive is introduced into the juice phase of the add cell and equilibrium is not attained before transfer, the partition ratio in the add cell will be greater than the equilibrium value. Similarly the partition ratio will exceed its equilibrium value in all cells where net transfer of additive is from the juice to the cossette phase, i.e., for all cells preceding the add cell, or for i less than m. On the other hand net transfer of additive is from the cossettes to the juice for cells after the add cell, hence the partition ratio for these cells will be less than the equilibrium value if equilibrium is not attained. Thus for all cells to have the same partition ratio, equilibrium must be reached since this ratio is approached from opposite directions in cells before and after the add cell. For the special case where equilibrium distribution of additive is not attained in each cell, but where one partition ratio (D) applies to all cells preceding the add cell and another partition ratio (d) to all cells after the add cell, $P = \frac{a}{1+X}$ where $X = \frac{(d^{n+1-m}-1)}{(d-1)} \frac{D^m}{(D^m-1)} (D-1)$. The additive contents of the individual cells are given by the expressions for the model battery with the appropriate value of D or d in place of d. The effect of additive distribution failing to reach equilibrium prior to transfer when additive is introduced into the juice phase is to increase the proportion of additive leaving the battery in the juice as compared to its value if distribution equilibrium had been attained.

Continuous Countercurrent Diffuser

The continuous countercurrent diffuser corresponding to the model battery defined above may be thought of as a model battery in which the number of cells is increased indefinitely and

the individual cell volume is proportionately decreased. Such a diffuser is referred to here as an ideal continuous countercurrent diffuser. In practice, however, the second assumption for a model battery cannot hold for the infinitely small cells thus hypothesized for the ideal continuous diffuser. It was shown above that this assumption is equivalent to attaining distribution equilibrium in each cell prior to transfer; in the case of the ideal continuous diffuser this is equivalent to having the oppositely moving streams of juice and cossettes in equilibrium with respect to distribution of additive at every point. Since such equilibrium cannot be established instantaneously in practice, this ideal continuous diffuser is of little interest.

In the theory of partition chromatography and distillation theory, the concept of equivalent theoretical plates has proved useful. For the present problem, we define an equivalent theoretical cell as a portion of a continuous countercurrent diffuser such that the concentration of additive associated with the juice leaving one end of the cell is that corresponding to distribution equilibrium with the concentration of additive associated with the cossettes entering the other end of the cell. The volume of an equivalent theoretical cell will be smaller the more intimate the mixing of the cossettes and juice as they travel in opposite directions and the lower their relative velocities. We continue to retain the assumptions made above for the model battery, with modifications appropriate for the continuous diffuser. The first assumption now means that the continuous diffuser has uniform cross section made up of the same area of juice and cossettes at all points with the rates of flow of each phase uniform throughout the diffuser. It is further assumed that the juice and cossettes each have a uniform concentration of additive over any cross section of the diffuser. In place of a single partition ratio applicable to all cells, a single distribution coefficient is assumed to apply to the equilibrium distribution of additive between cossettes and juice over the entire ranges of composition occurring in the continuous diffuser. The distribution coefficient c is defined as the ratio of the concentration of additive in juice to that in cossettes when the additive has reached distribution equilibrium between the two phases. A continuous countercurrent diffuser for which the above assumptions hold is referred to hereafter as a model continuous diffuser.

In order to illustrate the concept of equivalent theoretical cells and assist in its application to model continuous diffusers, let us examine qualitatively the case where equilibrium distribution corresponds to equal concentrations of additive in the juice

and the cossettes. Consider a model continuous diffuser of length λ in which juice flows from right to left (from $x = \lambda$ to $x = 0$), cossettes flow from left to right (from $x = 0$ to $x = \lambda$), and additive is introduced continuously into the juice at $x = \mu$. Let j_x and s_x be the concentration of additive at position x for the juice and cossette phases, respectively, and c the distribution coefficient, i.e. the equilibrium distribution value of j/s. Then the fact that equilibrium distribution of additive between the juce and cossettes is not attained instantaneously means that j_x/s_x is greater than c to the left of the add point and less than c to the right of the add point; in other words it must change sharply close to the add point. We also know this ratio to be infinite at the left end and zero at the right end of the diffuser when neither the battery supply water nor the fresh cossettes contain any additive. Thus qualitatively we have the situation shown in Figures 4 and 5 respectively for the general appearance of the ratio j_x/s_x and for j_x and s_x individually as a function of position in the diffuser. Both j_x and s_x are shown in Figure 5 as varying linearly with position in anticipation of results similar to those for model batteries with partition ratio of unity. The ratio j_x/s_x shown in Figure 4 corresponds to the concentrations shown in Figure 5. If back diffusion of additive in the juice is negligible, j is expected to show a sharp break at the add point.

Let us now place one theoretical cell boundary immediately to the right of the add point such that s has essentially its maximum value and j has its maximum value to the right of the

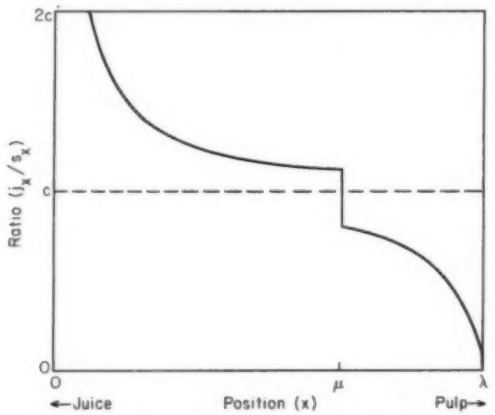

Figure 4.—Qualitative dependence of the steady state ratio of concentrations of additive in juice and cossettes on position in a model continuous countercurrent diffuser. Add point is at $x = \mu$.

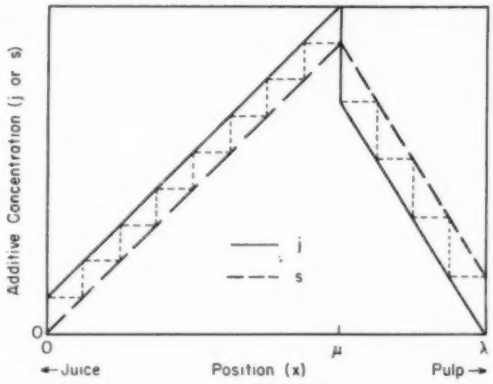

Figure 5.—Variation of steady state additive concentration in juice and cossettes in a model continuous countercurrent diffuser with partition ratio of unity. Add point is at $x = \mu$. Division of the diffuser into equivalent theoretical cells is indicated.

sharp break at the add point. Additional cell boundaries are then determined such that $j_{i-1}/s_i = c$ where j_{i-1} is the concentration of additive in the juice leaving the i^{th} cell and s_i is the concentration in the cossettes leaving the i^{th} cell. The locations of the boundaries thus determined are designated by the vertical dotted lines for the example of Figure 5. At steady state conditions, the distance along the axis of the diffuser corresponding to a theoretical cell is thus seen to be the distance separating the points in the juice and cossettes at which the additive concentrations have the same ratio as they would have at equilibrium. In Figure 5 this distance is shown as uniform along the length of the diffuser. It is shown in the appendix that all theoretical cells on either side of the add point have the same volume provided the distribution coefficient is constant. However, this volume may be different on the two sides of the add point if net transfer of additive between the juice and cossettes takes place more readily in one direction than the other. This latter situation is equivalent to a battery in which two different partition ratios apply respectively to cells before and after the add cell.

Let n designate the number of theoretical cells numbered serially from left to right such that m designates the theoretical add cell. Expressions for steady state conditions for the model continuous diffuser are then found to be similar to those for model batteries given above. Thus the concentrations of additive

associated with the pulp and juice leaving the diffuser are respectively

$$\mathrm{P} = \frac{a}{u_s}\left(\frac{d^m-1}{d^{n+1}-1}\right) \text{ and } \mathrm{J} = \frac{a}{u_j}\left(\frac{d^{n+1}-d^m}{d^{n+1}-1}\right)$$

where a is the amount per unit time of additive introduced continuously into the juice and d is the quantity $(u_j c/u_s)$ in which u_j and u_s are respectively the throughputs of the juice and cossettes in units of volume per unit time. The concentrations of additive in the juice and cossettes at positions in the diffuser corresponding to the theoretical cell boundaries are

$$j_i = \left(\frac{d^{i+1}-1}{d-1}\right)\frac{\mathrm{J}}{d^i}, \quad s_{i+1} = j_i/c \qquad (i = 0, \text{ to } m-1)$$

$$\text{and} \quad s_i = \left(\frac{d^{n+1-i}-1}{d-1}\right)\mathrm{P}, \quad j_{i-1} = cs_i \qquad (i = m \text{ to } n)$$

where $i-1$ and i refer to the left and right hand boundaries of the i^{th} cell. The total amount of additive in the diffuser at the steady state is approximately

$$\mathrm{T} = \frac{\mathrm{V}_s}{nu_s}\left(\frac{d'+1}{d-1}\right)\left[ma - (n+1)\ u_s\mathrm{P}\right] + \mathrm{V}_s\mathrm{P}\ \left(\frac{d'}{d}-1\right)$$

where d' is the quantity $(\mathrm{V}_j c/\mathrm{V}_s)$ and where V_j and V_s are respectively the volumes of juice and cossettes in the diffuser. It will be noted that this expression reduces to one similar to that for the model battery if $d' = d$, which is true when the throughput of each phase is proportional to the volume occupied by that phase in the diffuser at the steady state. Evaluation of these expressions for d equal to unity gives

$$u_s\mathrm{P} = \frac{ma}{n+1}, \quad u_j\mathrm{J} = \frac{(n+1-m)\,a}{n+1};$$

$$j_i = (i+1)\ \mathrm{J}, \quad s_{i+1} = j_i c \qquad (i = 0 \text{ to } m-1);$$

$$s_i = (n+1-i)\ \mathrm{P}, \quad j_{i-1} = cs_i \qquad (i = m \text{ to } n);$$

$$\text{and} \quad \mathrm{T} = \frac{(d'+1)\,\mathrm{V}_s}{2u_s}\ (n+1-m)\ ma + \frac{\mathrm{V}_s\mathrm{P}}{2}(d'-1).$$

The expressions given for T assume that all theoretical cells have the same volume. Derivation of these results is given in the appendix.

Relation to the Theory of Fractionation by Countercurrent Distribution

If instead of adding a single substance, a mixture of two substances were added, and if the partition coefficient of one were greater than unity and that of the other less than unity, Figure 3 indicates that these two substances might be efficiently separated with one leaving the battery in the juice and the other in the pulp. This is an example of separating two substances by countercurrent distribution, a technique which has been vigorously exploited in recent years. The distribution of additive in sugar beet diffusion batteries is thus seen to be a particular case of the more general problem of distribution of a substance between two immiscible phases moving countercurrent to each other. The steady state relations presented above are essentially the same as those which have been developed and applied in countercurrent extraction theory (1).

Time to Reach Steady State Conditions

Up to this point nothing has been said concerning how long is required to reach steady state conditions after introduction of additive is begun. Since steady state conditions are approached asymptotically, strictly speaking an infinite time is required. However some information on the approximate time required to approach steady state conditions can be obtained by considering the manner in which a single shot of additive becomes distributed in a battery subsequent to its introduction. Since this problem is related to the development of a band of a substance on a partition chromatographic column or in the tubes of a countercurrent distribution apparatus, the theory developed for those situations (2, 3, 4) can be applied to the present problem. After a number of transfers have been carried out subsequent to introduction of a single shot of additive, the latter becomes distributed among the various cells such that at any time there is a maximum amount in one cell with smaller amounts in other cells, the amount in any cell being less the farther the cell is from the cell containing the maximum. Except when the partition ratio is unity, the location of the cell containing the maximum moves further from the add cell as the number of transfers is increased, or the band is said to move away from the add point. The movement is toward the juice end for the partition ratio greater than unity. The number of transfers required to move this maximum out of a model battery is

$$t = \frac{m\,(d+1)}{(d-1)}$$ if d is greater than unity

and $t = \frac{(n-m)\,(1+d)}{(1-d)}$ if d is less than unity. The corresponding expressions for the time required to move the band of additive to the juice or pulp ends of a model continuous diffuser are respectively $t = \frac{\mu V_s\,(d'+1)}{u_s\,(d-1)}$ if d exceeds unity or $t = \frac{(\lambda-\mu)\,V_s\,(1+d')}{u_s\,(1-d)}$ when d is less than one. Symbols here have the same meanings as before. Further details are given in the appendix.

One may think of the distribution of additive in the diffuser at any time as the sum of the distributions of each portion of additive already introduced or the superposition of the bands due to successive additions. Since the number of transfers or time calculated by the above expressions represents the shortest period of operation to insure movement of the first band maximum out of the diffuser, it may be considered a minimum period for approaching steady state conditions. Each additional transfer or equivalent transfer time then results in an additional band maximum leaving the diffuser. If the number of transfers or time calculated by the above expressions is much larger than the number of cells or the mean throughput time of the juice and cossettes, one or two times this period may serve as a practical estimate of how long is required to reach steady state conditions. If such is not the case, several times the mean throughput time is suggested as a better estimate. The theory has been developed for quantitatively expressing the approach to steady state conditions (6), but is cumbersome to apply.

Both the shape of the band due to a single shot of additive and its maximum value as it leaves the battery or diffuser are related to the partition ratio d and the number of (theoretical) cells, the band becoming more spread out and the maximum becoming smaller the larger t. Although the expressions relating band maximum and band width to partition ratio and number of theoretical plates in partition chromatography are relatively simple, the corresponding relationships have not been developed in a form satisfactory for application to the diffuser problem considered here.

Discussion

The theoretical results presented above are probably most useful as a basis for understanding and predicting the manner in which a substance which is constantly introduced into a sugar beet diffuser becomes distributed within the diffuser and between the diffusion juice and the pulp. The effect of the partition ratio, the number of cells, and the location of the add point on the distribution has been discussed in conjunction with Figures 1, 2, and 3.

The mathematical expressions for the steady state presented above apply quantitatively only if the assumptions made in their derivation are known to be valid. Despite the fact that any beneficial effect of an additive presumably results from some chemical reaction, the assumption that there is no consumption of additive in the diffuser may be essentially true. Its validity can be ascertained either by direct measurement of the steady state additive content in the juice and pulp or by separate experiment. The design and method of operation of the diffuser will normally indicate if the assumption with regard to the constancy of the relative volume of juice and cossettes in the different portions of the diffuser is satisfied. In the case of the model battery, it was further assumed that the effective partition ratio is the same for all cells. It was pointed out that this implied that sufficient time was allowed between transfers for equilibrium distribution to be reached in each cell. This condition is not likely to be fulfilled in commercial practice with Roberts batteries, but it may be fairly closely approached. A single effective partition ratio for all cells also implies the applicability of a single distribution coefficient c for all parts of the diffuser. Distribution coefficients are in general dependent on the composition of the phases involved, the temperature, and the concentrations of the substance distributed. Whether the variations with respect to these properties in various parts of the diffuser produce significant variations in c must be considered for each additive of interest.

Use of the model battery steady state expressions to estimate the amount of additive in the diffusion juice, the pulp, or the various cells requires a knowledge of the partition ratio d. This is probably best determined directly under actual or simulated operating conditions. Direct measurement is also the best check on the constancy of d for different cells, particularly for cells before and after the add point. Of course d can be estimated by measuring any of the steady state quantities mentioned above if the pertinent assumptions are known to hold. If practically all

additive leaving the diffuser is associated with either the juice or the cossettes, this in effect places respectively a lower or upper limit on the effective partition ratios estimated from the additive content of the diffusion juice or the pulp.

For model continuous diffusers, u_j, u_s, V_j, V_s, and a are presumably known. This leaves d, n, and m as unknown quantities appearing in the steady state expressions presented above. However, since $d = u_j c/u_s$, it is a knowledge of c which is required. The distribution coefficient c is best found from separate equilibrium distribution measurements, but it can also be estimated from the time required for maximum additive concentration to leave the diffuser after a single shot has been introduced at a known position in accordance with the relation already discussed. There is apparently no simple way to estimate m and n independently of the steady state expressions. By measuring J or P and assuming that all theoretical cells have the same size on both sides of the add point $(m/n = \mu/\lambda)$, one can then estimate n and m from the appropriate steady state expression. These values would be minimum estimates if the flow of additive from the diffuser were essentially all from one end. If it is feasible to determine steady state concentrations of additive at selected points within the diffuser, the size of the theoretical cells can be determined from such measurements. Another approach to the problem is to determine m by steady state measurements when additive is introduced into the battery supply water and determine $(n\text{-}m)$ from similar measurements when additive is introduced with the fresh cossettes. Further discussion of these methods is given in the appendix.

If some additive from the pulp water is introduced with the battery supply water in addition to its introduction at another point in the diffuser, the steady state expressions applying are simply the sum of the appropriate expressions for supplying additive from each source separately.

Measurements have been made (5) on the lactic acid content of cell juices from Roberts batteries and continuous diffusers in which various patterns of distribution of acid among the cells were found. Although fermentation in more than one cell may have been responsible for these observed patterns, it is also clear that they could be approximated in model batteries such as discussed above with lactic acid generation occurring in only one cell.

Acknowledgment

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Dr. R. M. McCready, Dr. Stark, and other members of the Sugar Beet Unit of this Laboratory are gratefully acknowledged. Mrs. Floy Bracelin prepared the figures for publication.

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Appendix

Symbols used:

n = number of cells in the battery or number of equivalent theoretical cells in a continuous countercurrent diffuser.

i = integral subscript index running from 1 to n and designating the individual cells of a battery numbered serially with juice leaving the battery at $i = 1$, pulp at $i = n$. For continuous countercurrent diffusers i runs from 0 to n and designates the boundaries of the theoretical cells with juice leaving at $i = 0$ and pulp at $i = n$.

m = serial number of the add cell.

L_i, S_i = amounts of additive associated with the juice or the cossettes respectively in the i^{th} cell of a battery immediately prior to the next transfer under steady state conditions.

j_i, s_i = concentrations of additive in the juice or cossettes respectively at the indicated theoretical cell boundary in a continuous countercurrent diffuser at the steady state.

u_j, u_s = rate of movement of the juice or cossettes respectively through a continuous diffuser in units of volume per unit time.

V_j, V_s = total continuous diffuser volume occupied by juice or cossettes respectively.

a = quantity of additive introduced into add cell of a battery after each transfer or amount per unit time of additive introduced continuously in a continuous diffuser at the add point.

c = distribution coefficient = equilibrium value of j/s.

d = partition ratio. For batteries, $d = L_i/S_i$ immediately prior to the next transfer under steady state conditions. For continuous diffusers,

$$d = \frac{u_j c}{u_s},$$

$r = 1/d$.

J, P = amount of additive leaving the battery with the juice or the pulp respectively for each transfer under steady state conditions; for continuous diffusers the concentration of additive in the diffusion juice or pulp under steady state conditions.

A_i = total amount of additive in the i^{th} cell of a battery or the i^{th} theoretical cell of a continuous diffuser at the steady state.

T = total amount of additive in the diffuser under steady state conditions.

$$d' = \frac{V_j c}{V_s}.$$

x = position in continuous countercurrent diffuser with $x = 0$ being the juice end, $x = \lambda$ the pulp end, and $x = \mu$ the add point.

The following sections supply further details in reference to portions of the text under the same headings.

Model Battery

Transfer under steady state conditions must satisfy the following material balance equation for each cell except the first, last, and feed cells:

$$L_i + S_i = L_{i+1} + S_{i-1} \qquad (i = 2 \text{ to } m-1;\ m+1 \text{ to } n-1) \qquad (1)$$

The following equations similarly apply to the end cells:

$$S_1 + J = L_2 \qquad (2)$$

$$P + L_n = S_{n-1} \qquad (3)$$

Since $S_i = r\,L_i$, equations (1) and (2) can be rewritten to give

$$L_{i+1} = (1+r)\,L_i - rL_{i-1} \qquad (i = 2 \text{ to } m-1) \qquad (4)$$

$$L_2 = (1+r)\,J \qquad (5)$$

Putting $i = 2$ in equation (4) and making use of equation (5), we find

$$L_3 = (1+r+r^2)\,J \qquad (6)$$

Similarly putting $i = 3$ in equation (4) and making use of equations (5) and (6), we find

$$L_4 = (1+r+r^2+r^3)\,J \qquad (7)$$

Repeating this process we can find expressions for L_i for all values of i from 1 to m, viz.

$$L_i = (1+r+r^2+\ldots+r^{i-1})\,J \qquad (8)$$

The sum in parentheses may be expressed compactly by making use of the identity:

$$\sum_{i=0}^{k} z^i = \frac{z^{k+1}-1}{z-1}. \qquad (9)$$

This then gives the expression

$$L_i = \left(\frac{r^i-1}{r-1}\right) J \qquad (i = 1 \text{ to } m) \qquad (10)$$

Since $S_i = rL_i$ and $A_i = L_i + S_i$, we have the following expression for the total amount of additive in the i^{th} cell:

$$A_i = (1+r)\left(\frac{r^i-1}{r-1}\right) J = \left(\frac{d+1}{d-1}\right)(1-d^{-i})\ J \quad (i = 1 \text{ to } m) \tag{11}$$

Corresponding results are similarly obtained for the last $n-m$ cells of the battery. Since $L_i = dS_i$, equations (1) and (3) can be rewritten to give

$$S_{i-1} = (1+d)\ S_i - d\ S_{i+1} \quad (i = m+1 \text{ to } n-1) \tag{12}$$

$$S_{n-1} = (1+d)\ P \tag{13}$$

Proceeding as above, we find that

$$S_i = \left(\frac{d^{n+1-i}-1}{d-1}\right) P \quad (i = m \text{ to } n) \tag{14}$$

and $$A_i = \left(\frac{d+1}{d-1}\right)(d^{n+1-i}-1)\ P \quad (i = m \text{ to } n) \tag{15}$$

Since both equations (11) and (15) are valid for the add cell, we can equate these two expressions for A_m:

$$\left(\frac{d+1}{d-1}\right)(1-d^{-m})\ J = \left(\frac{d-1}{d+1}\right)(d^{n+1-m}-1)\ P \tag{16}$$

Replacing J by $a-P$ and solving for P, we find

$$P = \left(\frac{d^m-1}{d^{n+1}-1}\right) a \tag{17}$$

$$J = a-P = \left(\frac{d^{n+1}-d^m}{d^{n+1}-1}\right) a \tag{18}$$

The total amount of additive in the battery is then

$$T = \sum_{i=1}^{n} A_i = \sum_{i=1}^{m-1}\left(\frac{r+1}{r-1}\right) J\ (r^i-1) + \sum_{i=m}^{n}\left(\frac{d+1}{d-1}\right) P\ (d^{n+1-i}-1) \tag{19}$$

which can be written

$$T = \left(\frac{1+r}{1-r}\right) J\ \left(m - \sum_{i=0}^{m-1} r^i\right) + \left(\frac{d+1}{d-1}\right) P\ \left(m-n-2+\sum_{i=0}^{n+1-m} d^i\right) \tag{20}$$

When these sums are expressed as in equation (9) and J and r are replaced by $a-P$ and $1/d$ respectively, equation (20) simplifies to

$$T = \left(\frac{d+1}{d-1}\right)[ma - (n+1)\ P] \tag{21}$$

When $d = 1$, it is readily seen from equation (8) that

$$A_i = 2iJ \quad (i = 1 \text{ to } m) \tag{22}$$

Similarly the expanded form of equation (15) is seen to give

$$A_i = 2(n+1-i)\ P \quad (i = m \text{ to } n) \tag{23}$$

To evaluate P when $d = 1$, both the numerator and denominator of equation (17) are divided by $(d-1)$ and expressed as a summation using equation (9). This yields for $d = 1$

$$P = \frac{ma}{n+1}. \tag{24}$$

The total additive in the battery is then readily found to be

$$T = ma(n-m+1). \tag{25}$$

Some Non-Model Batteries

Suppose the juice and cossettes are not cleanly separated at transfer but the proportions of juice accompanying the cossettes and vice versa are each the same for all transfers. Let $L_i/S_i = d$ for clean separation and $L_i'/S_i' = D$ for this case. If the fraction of juice transferred with the cossettes is f_1 and the fraction of cossettes transferred with the juice is f_2,

$$D = \frac{L_i'}{S_i'} = \frac{(1-f_1)L_i+f_2S_i}{f_1L_i+(1-f_2)S_i} = \frac{(1-f_1)d+f_2}{f_1d+(1-f_2)} \tag{26}$$

Thus the net effect is to change the partition ratio from d to the value shown for D. All expressions for the model battery apply when this value of the partition ratio is used.

Suppose some of the contents of each cell are allowed to remain in the cell at each transfer but the material transferred in either direction and the residue are always in the same proportion. Again let $L_i/S_i = d$ for clean separation and $L_i'/S' = D$ for this case. If the fractions of juice and cossettes allowed to remain as residue are f_j and f_c respectively,

$$D = \frac{L_i'}{S_i'}. = \frac{(1-f_j)L_i}{(1-f_c)S_i} = \frac{(1-f_j)d}{(1-f_c)} \tag{27}$$

Again the net effect is to change the partition ratio from d to the value shown for D. The expressions for P, J, L_i, and S_i for the model battery still apply when the appropriate partition ratio is used. If a is the ratio of the amount of additive left in a cell to the amount removed at each transfer, it is clear that the model battery expressions for the amount of additive in each cell and for the total amount of additive in the battery must be increased by the factor $(1+a)$. In terms of the symbols used here,

$$1 + a = \frac{D+1-Df_c-f_j}{(D+1)(1-f_j)(1-f_c)} \tag{28}$$

For the case where partition ratio D applies to the first m cells and partition ratio d applies to the last m-n cells, equations (10), (11), (14), and (15) apply where $r = 1/D$ and $d = d$. When expressions for A_m of equations (11) and (15) are equated as in equation (16) and P and J are solved for as in Equations (17) and (18), the result is

$$P = \frac{a}{1+X} \text{ and } J = \frac{aX}{1+X} \tag{29}$$

where X has the value given in the text.

Continuous Countercurrent Diffuser

Under steady state conditions the rate at which additive enters each cell is balanced by the rate at which it leaves. This yields a set of material balance equations similar to Equations (1), (2), and (3), viz.

$$j_i u_j + s_{i+1} u_s = j_{i+1} u_j + s_i u_s \qquad (i = 1 \text{ to } m-2;\ m \text{ to } n-2) \tag{30}$$

$$\mathrm{J} u_j + s_1 u_s = j_1 u_j \tag{31}$$

$$j_{n-1} u_j + \mathrm{P} u_s = s_{n-1} u_s. \tag{32}$$

The same procedure used in deriving the model battery equations yields

$$j_i = \left(\frac{r^{i+1}-1}{r-1}\right)\mathrm{J}, \qquad (i = 0 \text{ to } m-1) \tag{33}$$

$$s_i = \frac{(d^{n+1-i}-1)}{(d-1)}\ \mathrm{P} \qquad (i = m \text{ to } n) \tag{34}$$

The additive contents of the cossettes and juice leaving each theoretical cell are related by $j_{i-1} = cs_i$ ($i = 1$ to n). In particular $s_m = j_{m-1}/c$, so that equations (33) and (34) can each be used to express s_m. When these two expressions for s_m are equated and the relation $a = u_j \mathrm{J} + u_s \mathrm{P}$ is used, the results are

$$\mathrm{P} = \frac{a}{u_s}\left(\frac{d^m-1}{d^{n+1}-1}\right) \text{ and } \mathrm{J} = \frac{a}{u_j}\left(\frac{d^{n+1}-d^m}{d^{n+1}-1}\right). \tag{35}$$

The total amount of additive in the diffuser at the steady state is estimated by Simpson's rule for the case where all theoretical cells of the diffuser have the same volume. For each theoretical cell

$$\mathrm{A}_i = \frac{\mathrm{V}_j}{2n}\ (j_{i-1}+j_i) + \frac{\mathrm{V}_s}{2n}\ (s_{i-1}+s_i) \tag{36}$$

except for the add cell where

$$\mathrm{A}_m = \frac{\mathrm{V}_j}{2n}\ (j_{m-1}+j_{\max}) + \frac{\mathrm{V}_s}{2n}\ (s_{m-1}+s_m). \tag{37}$$

Here $j_{\max}$ is estimated from equation (33) with $i = m$. When the values for j and s given by equations (33) and (34) are inserted and the summation $\mathrm{T} = \sum_{i=1}^{n} \mathrm{A}_i$ is carried out in a manner similar to that used in obtaining equation (21) the result is

$$\mathrm{T} = \frac{\mathrm{V}_s}{nu_s}\left(\frac{d+1}{d-1}\right)\ [ma-(n+1)\,u_s\mathrm{P}] + \mathrm{V}_s\mathrm{P}\ \left(\frac{d'}{d}-1\right) \tag{38}$$

The corresponding relations when the partition ratio is unity are found in the same way as for the model battery to be those given in the text.

Evaluation of the above expressions for j_i, s_i, J, P, and T for countercurrent continuous diffusers with partition ratio of unity is carried out in a manner similar to that used for the model battery with $d = 1$. The results are given in the text.

To verify that all theoretical cells on the same side of the add point have the same volume, let us assume for the moment that this is true. Then equations (33) and (34) can be written

$$j_x = \left(\frac{rx+1-1}{r-1}\right) \text{J and } s_x = j_{(x-1)}/c \qquad (39)$$

to express the concentration of additive in the juice and cossettes at any point between $x = 0$ and $x = \mu$. Where x is expressed in units of μ/m. Since these relations satisfy the differential materials balance relation $u_j\left(\frac{dj_x}{dx}\right) = u_s\left(\frac{ds_x}{dx}\right)$, the assumption of equal theoretical cell volumes is validated for the portion of the diffuser to which the relations used for j_x and s_x apply. In the same way the theoretical cells on the other side of the add point are shown to each have the same volume, but this volume is not necessarily the same on the two sides of the add point.

Time to Reach Steady State Conditions

The distribution of additive in each cell of a model battery prior to the next transfer can be described as fraction p in the juice and fraction $q = 1-p$ in the cossettes, where $p = \frac{d}{1+d}$ and $q = \frac{1}{1+d}$. Each transfer tends to move fraction p of the additive in each cell in one direction and fraction q in the other. For a single portion of additive introduced into the add cell, the effect of succeeding transfers will be to move additive toward the juice end of the battery p times as fast as the juice and toward the pulp end q times as fast as the cossettes. The net rate of movement of the maximum additive concentration will be toward the juice end if p is larger than q at an average of $p-q$ cells per transfer. Thus to move the maximum a distance of m cells requires $m/(p-q) = m\left(\frac{d+1}{d-1}\right)$ transfers. Likewise if the partition ratio is less than unity, $\frac{(n-m)}{(q-p)} = (n-m)\ \frac{1+d)}{(1-d)}$ transfers are required to move the maximum out of the pulp end of the battery. In the continuous countercurrent diffuser, equilibrium distribution of additive between juice and cossettes corresponds to fraction $p = \frac{V_j j}{V_j j+V_s s} = \frac{d'}{d'+1}$ in the juice and fraction $q = 1-p = \frac{1}{d'+1}$ in the cossettes. The linear velocities of the juice and cossettes are $\frac{u_j}{V_j}$ and $\frac{u_s}{V_s}$ respectively. The net rate of movement of the maximum concentration of additive due to a single injection of additive is accordingly $p\frac{u_j}{V_j} - q\frac{u_s}{V_s}$ The time necessary to travel to the juice end of the diffuser if p is greater than q is then

$$t = \frac{\mu}{p\,\frac{u_j}{V_j} - q\,\frac{u_s}{V_s}} = \frac{\mu V_s (d'+1)}{u_s (d-1)} \quad . \tag{40}$$

Likewise if d is less than unity, the time required for the band to travel to the pulp end is

$$t = \frac{(\lambda-\mu)\ V_s (1+d')}{u_s (1-d)} \quad . \tag{41}$$

Discussion

If measurements of additive concentration at the steady state can be made at selected points within a model continuous diffuser, the equivalent theoretical cell volumes can be found by use of equation (39) and the similar equation applying for the other side of the add point. Suppose j_y and j_z is the measured steady state concentration of additive in the juice at points $x = y$ and $x = z$ between $x = 0$ and $x = \mu$. If $z/y = R$, from equation (39)

$$\frac{j_y}{j_z} = \frac{r^y+1-1}{r^{Ry}+1-1} \cdot \tag{42}$$

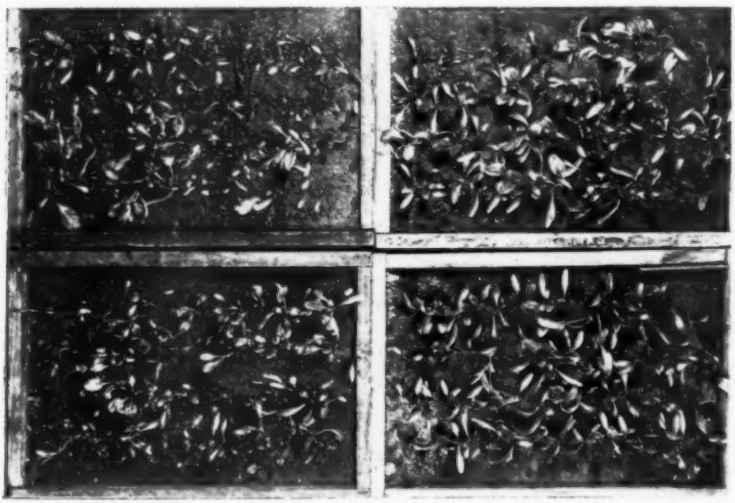
It is assumed that r has been determined. The value of y satisfying equation (42) then gives the number of theoretical cells between $x = 0$ and $x = y$, and hence the volume of each cell. If $J = j_o$ is used as j_z, only one measurement is needed within the diffuser. A similar procedure is used to determine theoretical cell volume for the other side of the add point.

If additive is introduced with the supply water instead of at the normal add point, y and z of equation (42) may be taken as the two ends of the diffuser. Then $J/a = \frac{r^{n_j}+1-1}{r-1}$, from which n_j is found. The volume of each theoretical cell on the juice discharge side of the normal add point is then the total diffuser volume divided by n_j. Similarly if additive is introduced with the fresh cossettes instead of at the normal add point, $P/a = \frac{d^{n_s}+1-1}{d-1}$, from which n_s is found. The volume of each theoretical cell on the pulp discharge side of the normal add point is then the total diffuser volume divided by n_s.

Notes Section

Factors Affecting Cold Resistance. A test in which seedlings of six different ages, 20 to 40 days, and of two hardening treatments, 3 and 7 days, were frozen at —8° C for 1 and 1½ hours indicated that seedlings (1) get progressively more cold susceptible with age (2) get more resistant with longer hardening time and that (3) longer freezing kills more than shorter freezing time. Seedlings in the cotyledon stage were very frost resistant.

In testing inbreds from the Performance test, it became evident that stage of development was perhaps more of a factor in cold resistance than age alone. The weaker and slower growing inbreds were tougher than the larger ones of the same age.



Flats of seedlings frozen for 1 hour at —8° C. Two flats on left heavily watered 15 hours before freezing; flats on right watered 4 days before freezing.

In another test, the flats containing the seedlings were watered heavily about 15 hours before freezing. Plants in lots which had been watered soon before freezing were much more cold susceptible than ones having less but sufficient moisture. This reaction lasted less than 24 hours.

Two inbreds, one observed to be frost susceptible and one frost resistant in the field in the mature stage, were equally susceptible in the seedling stage.

R. K. OLDEMEYER, PLANT BREEDER
AGRICULTURAL EXPERIMENT STATION
THE GREAT WESTERN SUGAR COMPANY

Apparatus Used to Control Pollination of Sugar Beets[1]—Two of the problems in controlling pollination of sugar beets are collecting sufficient amounts of pollen and transferring the pollen to the dispenser. The purpose of this article is to describe the apparatus[2] used in sugar beet breeding at Fort Collins, Colorado, which, to a considerable extent, tends to solve both of these problems.

The apparatus collects the pollen and deposits it in the dispenser. The collector and dispenser are shown in Figure 1.

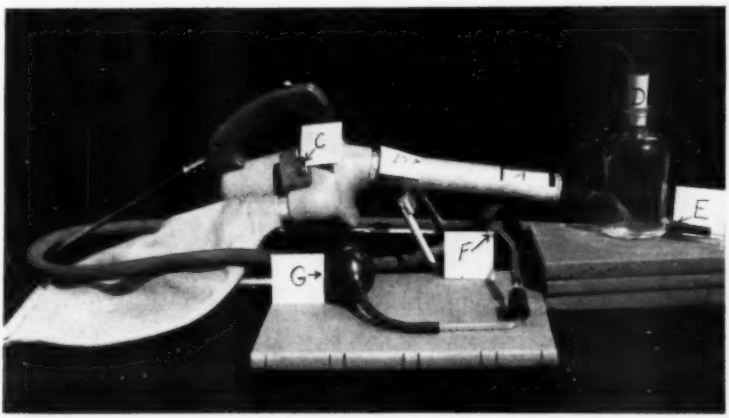


Figure 1.—Pollen Collector and Dispenser.—A. Air vent. B. Sliding collar. C. Deflector for motor cooling system. D. Mouth of dispenser bottle where filter is used during pollen collection. E. Tubular opening at base of bottle through which pollen travels both in collecting and in distributing operations. F. Bend in tubing to cause swirling motion of pollen in the bottle when used as a dispenser. G. Bulb to provide air pressure when using bottle as a dispenser.

The collector is composed of a small vacuum cleaner, a galvanized steel tubular part with an air vent, a deflector, and rubber tubing. The purpose of the air vent in the tubular part is to control air suction to such an extent that the pollen is pulled off the flowers through the small tubular opening at the base of the dispenser; but at the same time the air motion inside the dispenser is reduced sufficiently to allow the pollen to be deposited in the bottle. The sliding collar makes the air vent adjustable for size and suction. The air being brought into the dispenser finally passes from the mouth of the bottle into the

[1] Cooperative investigations of the Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, and the Colorado Agricultural Experiment Station. Approved by the Colorado Agricultural Experiment Station for publication as Scientific Series Article No. 516.

[2] Apparatus was developed in connection with sugar beet breeding conducted by Dr. LeRoy Powers.

tubular part and from there into the bag of the vacuum cleaner. The deflector prevents the air from the motor cooling system of the vacuum cleaner from disturbing the pollen on plants from which collections are being made and from spreading pollen which may be undesirable in the greenhouse. Sometimes it has been found desirable to use a cloth filter over the mouth of the dispenser bottle to prevent the escape of pollen as the air passes through it into the bag of the vacuum cleaner.

The dispenser, developed by Dr. R. K. Oldemeyer of the Great Western Sugar Company, consists of an aspirator bottle, glass tubing, and rubber bulb, as shown in Figure 1. The lower end of the glass tube is bent to impart a swirling motion to pollen near the bottom of the dispenser when air pressure is applied from a rubber bulb attached to the tube. The air pressure from the rubber bulb blows the pollen out through the small tubular opening at the base of the aspirator bottle.

The pollen is applied from the dispenser to the bagged flowers through a small slit made in one of the creases of the bag. After application of pollen this slit is closed by a folded piece of paper which is held in place by a paper clip.

In the greenhouse, pollen can be readily collected from non-bagged flowers or from within a bag that has been placed over flowering branches. The collection of pollen from a bag is accomplished through a long piece of glass tubing inserted into the bag through a small slit. A window of clear plastic material should be provided in those bags on flowering branches for the purpose of collecting pollen.

The apparatus was used for pollinations in the Sugar Crops Section's greenhouses at Fort Collins during the winter of 1956-57 and proved very satisfactory.

E. D. KROUCH, J. P. KINTZLEY, and R. D. TAYLOR
Agricultural Aids, Crops Research Division
ARS, USDA, Fort Collins, Colorado.

Leafspot Resistance. Leaves of leafspot resistant plants in a segregating population involving US 201 showed necrosis of the parenchymatous tissue when observed by transmitted light. No necrosis was evident on the surface of the leaf. Perhaps this indicates the resistance of US 201 is due at least in part to supersensitivity.

R. K. OLDEMEYER, PLANT BREEDER
AGRICULTURAL EXPERIMENT STATION
THE GREAT WESTERN SUGAR COMPANY

Bolting Resistance. Inbred lines vernalized until some bolters began to appear, then forced, revealed clear-cut differences between lines as to bolting resistance. This technique would perhaps be more efficient than field selection.

Flat of S_1 sugar beet inbreds showing variation in bolting following vernalization. Left, 100 percent bolting; center, no bolting; right, segregating for bolting.

R. K. OLDEMEYER, PLANT BREEDER
AGRICULTURAL EXPERIMENT STATION
THE GREAT WESTERN SUGAR COMPANY